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UNITED STATES NAVY
OCEANIC ARMED RECONNAISSANCE SYSTEM

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14. **ABSTRACT** A student team at the Naval Postgraduate School studied the need for, and development of, a system that effectively and economically deters piracy in an area of interest. The system‟s proposed area of operation is the Gulf of Aden, but the system may be deployed to any operational theater where piracy threatens maritime commerce. Piracy and hijacking of ships off the Somali Coast have grown tenfold since 2006. In response to this growing problem, the U.S. Navy, along its with allies, formed Combined Task Force 151 (CTF-151) to protect approximately 33,000 merchant vessels transiting through this area daily. CTF-151 patrols the Internationally Recommended Transit Corridor (IRTC) in the Gulf of Aden and because of this, Somali pirates have begun to migrate away from the IRTC and CTF-151 patrols. For this reason, the team studied the use of UAV technology that allowed for broader area of piracy surveillance and detection. The system that was conceived and analyzed was the Oceanic Armed Reconnaissance System (OARS). The OARS Basic alternative, when analyzed against CTF-151, was found to be the most cost effective system. This OARS Basic system is comprised of a Littoral Combat Ship (LCS) as a host vessel, ScanEagle UAVs, an SH-60 Helicopter, and Zodiac Rigid Hulled Inflatable Boats (RHIB).

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ABSTRACT

A student team at the Naval Postgraduate School studied the need for, and development of, a system that effectively and economically deters piracy in an area of interest. The system"s proposed area of operation is the Gulf of Aden, but the system may be deployed to any operational theater where piracy threatens maritime commerce. Piracy and hijacking of ships off the Somali Coast have grown tenfold since 2006. In response to this growing problem, the U.S. Navy, along its with allies, formed Combined Task Force 151 (CTF-151) to protect approximately 33,000 merchant vessels transiting through this area daily. CTF-151 patrols the Internationally Recommended Transit Corridor (IRTC) in the Gulf of Aden and because of this, Somali pirates have begun to migrate away from the IRTC and CTF-151 patrols. For this reason, the team studied the use of UAV technology that allowed for broader area of piracy surveillance and detection. The system that was conceived and analyzed was the Oceanic Armed Reconnaissance System (OARS). The OARS Basic alternative, when analyzed against CTF-151, was found to be the most cost effective system. This OARS Basic system is comprised of a Littoral Combat Ship (LCS) as a host vessel, ScanEagle UAVs, an SH-60 Helicopter, and Zodiac Rigid Hulled Inflatable Boats (RHIB).

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ACRONYM LIST

Acronym	Term
AHP	Analytic Hierarchy Process
AIS	Automatic Information System (Ship Traffic)
AoA	Analysis of Alternatives
APB	Acquisition Program Baseline
ASR	Alternate System Review
BAMS	Broad Area Maritime Surveillance
C2	Command and Control
C3I	Command, Control, Communications and Intelligence
CAIV	Cost as an Independent Variable
CDD	Capability Development Document
CPM	Critical Path Method
CO	Commanding Officer
CONOPS	Concept of Operations
COP	Common Operational Picture
COSAL	Consolidated Shipboard Allowance List
COTS	Commercial Off-The-Shelf
CTF	Combined Task Force
DoD	Department of Defense
DORNA	Dirección de tiro Optrónica y Radárica NAval
DDG	Guided Missile Destroyer
ESOH	Environmental Safety and Health
FAA	Functional Area Analysis
FFBD	Functional Flow Block Diagram
FOUO	For Official Use Only
FSA	Functional Solution Analysis
FTA	Fault Tree Analysis
FY	Fiscal Year

GAO	Government Accountability Office
GOTS	Government Off-The-Shelf
GPS	Global Positioning System
HMI	Human Machine Integration
HOQ	House of Quality
ICC	International Criminal Court
ICD	Initial Capabilities Document
IDEF	Integration Definition
ILS	Integrated Logistics Support
IMB	International Maritime Bureau
IPR	Interim Project Review
IPT	Integrated Product Team
ITR	Initial Technical Review
JITC	Joint Interoperability Test Command
IRTC	Internationally Recognized Transit Corridor
ISEA	In-Service Engineering Agent
KPP	Key Performance Parameter
LCC	Life Cycle Cost
LCS	Littoral Combat Ship
LPD	Landing Platform Dock
MOE	Measure of Effectiveness
MOP	Measure of Performance
M&S	Modeling and Simulation
NAVAIR	US Navy Naval Air Systems Command
NAVICP	Naval Inventory Control Point
NAVSEA	US Navy Naval Sea Systems Command
NPS	Naval Postgraduate School
NRL	Naval Research Laboratory
NSA	National Security Agency
NSS	Naval Simulation System

NSWC	Naval Surface Warfare Center
NUWC	Naval Undersea Warfare Center
OARS	Oceanic Armed Reconnaissance System
PARS	Pirate Attack Risk Surface (Software)
PDT	Product Delivery Team
P_h	Probability of Hit
P_k	Probability of Kill
PHD	Port Hueneme Division
PM	Program Manager
PMBOK	Project Management Body of Knowledge
PMP	Project Management Plan
POC	Point of Contact
POM	Program Objective Memorandum
QFD	Quality Function Deployment
RHIB	Rigid Hulled Inflatable Boat
RPG	Rocket Propelled Grenade
RRM	Risk Reporting Matrix
SA	Situational Awareness
SCA	Software Communication Architecture
SE	System Engineering
SEI	Specific Emitter Identification
SFR	System Functional Review
SME	Subject Matter Expert
SPAWAR	Space and Naval Warfare Systems Command
SoS	System of Systems
SRR	System Requirements Review
TDA	Technical Design Agent
TRL	Technology Readiness Level
TTP	Tactics, Techniques, and Procedures
UAS	Unmanned Aerial Support or Unmanned Aerial Systems

UAV	Unmanned Aerial Vehicle
UCS	Unmanned Combat System
UNREP	Underway Replenishment
USB	Universal Serial Bus
USN	US Navy
USNR	US Navy Reserve
USS	US Ship
VBSS	Visit, Board, Search, Seizure
VTUAV	Vertical Take-Off Unmanned Aerial Vehicle
WBS	Work Breakdown Structure
XO	Executive Officer
ZMB	Zwicky‟s Morphological Box

EXECUTIVE SUMMARY

Piracy and hijacking of ships off the Somali Coast has increased drastically over the last five years. In an attempt to counter these pirate acts and provide friendly cargo vessels with safe passage through the Gulf of Aden, the U.S. Navy, along with its allies, formed Combined Task Force 151 (CTF-151). This task force provides safe passage for cargo vessels by patrolling a narrow strip of the Gulf of Aden, called the Internationally Recommended Transit Corridor (IRTC). CTF-151‟s presence along the IRTC has driven pirates further away into other areas of the Gulf of Aden and the Indian Ocean.

As Systems Engineering students studying at the Naval Postgraduate School, this problem was brought to our attention and became the focal point of our research. The need for an anti-piracy system with a larger area of coverage became evident. From this need, our team decided to investigate the use of Unmanned Aerial Vehicle (UAV) technology to aid in covering a larger area of ocean. The system that was conceived and analyzed was called the Oceanic Armed Reconnaissance System (OARS).

At the end of our research and analysis, the system that was found to be the most cost effective in regards to piracy detection and deterrence was the “OARS Basic” alternative. The subsystem components that comprise OARS Basic are a Littoral Combat Ship (LCS), ScanEagle UAVs, an SH-60 Helicopter, and Zodiac Rigid Hulled Inflatable Boats (RHIB). Performance of six of these OARS Basic systems were compared against the current CTF-151ships.

Our research team began our work by first outlining the scope of the problem and by researching current technology. After outlining the scope of the problem and conducting a technology feasibility analysis, our team then developed a concept of operations (CONOPs) for two different OARS variations, OARS Basic and OARS Augmented. These concepts included the use of an array of existing UAV technology, which would be integrated into a host vessel platform. Besides being used for surveillance and reconnaissance, the UAVs will also collect live-video of pirate activity, which will provide stronger evidence in court for convicting pirates of crimes.

The goal of the host vessel was to provide surveillance and interdiction of pirate activity, which could be supplemented with pursuit and interdiction craft, such as RHIBs and helicopters. The OARS Augmented alternative included everything from the Basic OARS alternative, but also utilized a long range airship or Broad Area Maritime Surveillance (BAMS) UAV to increase detection and surveillance potential. The feasibility of these systems was supplemented by information from subject matter experts and stakeholders.

The team conducted a House of Quality (HOQ) analysis to quantify which design characteristics were most critical to the stakeholders. The team determined that Detect and Track were the most valuable design characteristic, as indicated from the associated weighted metrics. To gauge the effectiveness of these design characteristics during OARS system modeling and design, twelve Key Performance Parameters (KPPs) were selected from a pre-determined list of Measures of Performance (MOPs). Some of these KPPs included percent of pirate detection, coverage area, intercept time, and number of engagements. These twelve KPPs became the test metrics for system comparison during the modeling and simulation phase.

After the functional and physical architectures had been derived, the team generated seven alternatives for physical OARS systems. These seven alternatives were comprised of different combinations of OARS subsystems. Each alternative outlined specific guns, missiles, communication systems, radars, sensor equipment, vessels, helicopters, and UAVs, all of which are currently mature systems. In an effort to facilitate rapid deployment and reduced cost, only existing warfare systems with high technology readiness level (TRL) were considered as subsystem variants. The critical variants considered in this process were the host vessel, helicopter, pursuit vessel, and UAV.

The emergent preferred alternative, which we deemed as "OARS Basic," incorporated the use of an LCS host vessel, a SH-60 helicopter, Zodiac RHIBs as pursuit vessels, and ScanEagle UAVs. The team also indicated a second alternative, referred to as "Augmented OARS," which incorporated a BAMS UAV for additional aerial surveillance.

Using these two identified alternatives, OARS Basic and Augmented OARS, the team built models of each and simulated their operations using the Naval Simulation System (NSS) software. Each scenario contained the same environmental modeling parameters, which consisted of: 355 transiting cargo vessels, 100 pirate motherships, and 200 pirate skiffs. The model environments spanned 390,000 square miles of ocean in the Gulf of Aden and simulated anti-piracy operations during a 30 day period. During data analysis, the team focused on particular NSS data measurements which were relevant to original stakeholder MOEs. OARS Basic proved to be slightly more capable of neutralizing and deterring pirate motherships, while also detecting 35% more pirates than CTF-151. This is attributed to the fact that OARS Basic had four times more airborne UAVs than CTF-151 and suggests that simply the presence of UAVs deters pirate activity.

During the last week of modeling and simulation runs, the OARS team‟s modeling and simulation databases were inadvertently erased. This resulted in the loss of all software models and prohibited the OARS team from extracting the modeling results of the OARS Augmented alternative. For this reason, CTF-151 was only compared against the OARS Basic alternative.

The cost analysis showed that OARS Basic has a Life Cycle Cost (LCC) of $15.5B, which is 12% cheaper than CTF-151‟s LCC of $17.5B. Using these LCCs and the effectiveness results from the modeling and simulation analysis, the OARS team recommends the OARS Basic alternative to be utilized in future anti-piracy missions.

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I. INTRODUCTION

A. OBJECTIVE

The objective of this project was to develop a system that effectively and economically deters piracy in an area of interest. The system"s current area of operation is the Gulf of Aden, but the system may be deployed to any operational theater where piracy threatens maritime commerce.

B. BACKGROUND

Piracy has re-emerged as a problem to the international maritime community. Piracy is a worldwide concern for all vessels traveling the open seas. Piracy is defined as consisting of:

> *"…any of several acts, including any illegal act of violence or detention, or any act of depredation, committed for private ends by the crew or the passengers of a private ship and directed against another ship, aircraft, persons, or property onboard another ship on the high seas; or against a ship, persons or property in a place outside the jurisdiction of any state"* (Maritime Security: Actions Needed to Assess and Update Plan…, GAO 2011).

Although piracy could happen anywhere across the global seas, piracy near the shores of Somalia, including the Gulf of Aden, Southern Somalia Basin, and Western Indian Ocean, has grown in staggering proportion over the last five years. Table 1 illustrates the growing numbers of Somalia based pirate attacks over the last 5 years (United States General Accountability Office (GAO), "Maritime Security: Updating U.S. Counterpiracy Action Plan… 2011). In 2006, Somali Piracy accounted for only 9% of the global piracy attempts. Today, Somali Piracy accounts for over 60% of the worldwide total pirate attempts (International Maritime Bureau, 2011).

Modern day pirates are usually armed with very intimidating weaponry, including long knives, AK-47 assault rifles, and Rocket Propelled Grenades (RPGs). Somali pirates are not centrally controlled, but have a common mission. That mission is to hijack high value ships, hold the crew members hostage, and extort millions of dollars in ransom money. Hundreds of attacks are recorded each year. Pirates have captured dozens of

ships, held thousands of hostages, and have cost the maritime community severely in losses and spent revenue (IMB Piracy Report 2010-2011).

Pirates utilize motherships and smaller skiffs to commit piracy acts. The motherships can be any large vessel, including fishing vessels, yachts, or large industrial vessels that have recently been hijacked. When a target vessel is spotted, the pirates launch the smaller skiffs and proceed to board and hijack the vessel. Pirate skiffs usually carry between four and eight passengers, can have twin out-board engines, contain large quantities of fuel, and often contain ladders and grappling hooks for boarding. Depending on the victim vessel, pirates can board and take over a vessel in less than 20 minutes (GAO, "Maritime Security: Updating U.S. Counterpiracy Action Plan, 2011).

1. Current Anti-Piracy Solutions

The Combined Task Force 151 (CTF-151) is currently deployed within the Gulf of Aden to combat piracy. CTF-151 is a multinational task force that was established in 2009 to conduct counter-piracy operations. In the Gulf of Aden, CTF-151 patrols the Internationally Recommended Transit Corridor (IRTC). The IRTC is a narrow passage way through the Gulf of Aden that was created after piracy escalated in the area (Combined Maritime Forces 2011). The IRTC allows CTF-151 to concentrate its patrols and has helped to deter some piracy in the Gulf of Aden, but unfortunately, piracy still remains a threat to everyone who transits near the Horn of Africa. CTF-151 patrols the IRTC and even escorts merchant vessels from time to time. However, most of CTF-151‟s anti-piracy operations are initiated by distress calls from merchant vessels that are already being attacked by pirates.

2. Current Limitations to Combating Somali Piracy

What makes Somali Piracy difficult to counter is the pirates‟ lack of definitive characteristics that separate them from the fishermen and civilians. The fact is that most Somali pirates are ex-fishermen and operate on fishing vessels. The Horn of Africa, especially within the Gulf of Aden, is a very popular fishing area to the natives. This means that there are a multitude of innocent fishing vessels in the area, which makes it

very difficult for anyone to identify pirates before they actually commit a crime (Christensen 2009).

Another downside to effectively combating piracy is the maritime legal restrictions placed upon naval forces when facing pirates.

> *"A state of war does not exist therefore the law of armed conflict does not apply – pirates cannot be targeted as if they were combatants. Force can only be used against pirates in either self-defense / defense of others or to stop the vessel in order to board it – its use must be avoided as far as possible and, where unavoidable, must not go beyond what is reasonable and necessary in the circumstances"* (Christensen 2009).

This makes it difficult to stop piracy in its tracks. Even when a distress call is received and the pirates are intercepted by CTF-151, it is hard to collect incriminating evidence against the pirates to convict them of any crimes. This is due to the fact that pirates will often throw their paraphernalia (weapons, ladders, ammunition, etc.) overboard if they spot CTF-151 naval vessels.

3. UAV Technology in the Deterrence of Piracy

In order to combat these deficiencies, the OARS Capstone team pursued the use of UAV technology in anti-piracy operations. The use of UAV technology in anti-piracy operations will allow for:

- A broader area of surveillance coverage. This allows the OARS system to be easily transferable to other pirate-infested waters, and ultimately, anywhere in the world where piracy is an issue.
- A better source of video-footage and imagery of pirate vessels. These images and video surveillance can be used as incriminating evidence against the pirates to ensure that when caught, they will serve jail time for their intentions and not just be "caught and released," as is the current norm. Even though it is often difficult to determine whether or not a vessel is a pirate vessel, there are some tell-tale signs that the UAVs can search for that can aid in determining suspicious vessels. These are: long ladders, large quantities of fuel drums, guns and ammunition crates, and large quantities of men (upwards of 8 to 10 men in a single small skiff).
- An ever-present "eye in the sky" mentality that will keep the pirates always looking over their shoulder. The fact that the pirates know that they could be under surveillance at any given time by UAVs will make them less willing to commit acts of piracy.

C. SCOPE AND ASSUMPTIONS

1. Scope

Pirates use a flexible mode of operation and operate in an area that spans hundreds of square miles. They can lay dormant in an area for weeks or attack almost daily against any ship within their range.

Due to its large concentration of ship traffic and its proximity to the Somali coast line, the Gulf of Aden has been the main focus of Somali piracy attempts. Table 1 shows the number of piracy attempts that are attributed to Somali Pirates.

Table 1. Locations of All Attempted and Actual Somalia Piracy Acts from 2006 to 2011 (From IMB Piracy Report, 2010-2011).

	Locations	2006	2007	2008	2009	2010	2011 (Jan - June, 6 months)
	Somalia	10	31	19	80	139	125
	Gulf of Aden	10	13	92	117	53	20
	Red Sea				15	25	18
REST OF	Arabian Sea	2	4		1	2	
WORLD	Indian Ocean				1		
	Oman		3		4		
	Yearly Totals of SOMALIAN PIRATE Attacks/Attempts	22	51	111	218	219	163
	Yearly Totals of WORLD WIDE Attacks/Attempts	239	263	293	410	445	266
	Percentage of SOMALIAN PIRATE Attacks vs. the WORLD WIDE Totals	9%	19%	38%	53%	49%	61%

Due to the fact that the Gulf of Aden is a natural chokepoint and that over 33,000 ships transit its waters every year, the OARS team focused on prevention of piracy within the Gulf of Aden (GAO, "Maritime Security: Updating U.S. Counterpiracy Action Plan, 2011).

2. Assumptions

To meet such a challenge, the OARS team developed the following list of initial system needs and assumptions:

The OARS system should:

- Focus on the Gulf of Aden similar to CTF-151.
- Adhere to the Navy"s Seapower-21 concept and its net-centric maritime domain awareness doctrine.
- Be deployable by 2020 and capable of defending all shipping from piracy, within the current 1.1 million square mile operational area of CTF-151.
- Be capable of neutralizing pirates and then arresting, detaining & maintaining evidence for continued prosecution.
- Be developed jointly with international interests.
- Be supportable by current DoD logistics systems.
- Have increased use of ship borne UAV platforms (Off the shelf UAVs, where any modifications would be limited).
- Utilize non lethal UAV deterrence (Where pirates will get the message but not be killed).
- Comply with International Law.
- Developed as cost effectively as possible.

D. SYSTEMS ENGINEERING METHODOLOGY AND APPROACH

The OARS system engineering process consisted of Mission Conceptualization, Concept of Operations, Requirements Analysis, System Development, System Analysis, System Verification, System Integration, and Recommendations.

The OARS team utilized the systems engineering "Vee" diagram as a guideline for creating a tailored system engineering process. The classic "Vee" was then adapted to fit our unique anti-piracy mission, to meet the need for early mission development, to be consistent with our capstone schedule, and to meet the goals and focus of our Modeling and Simulation effort. Figure 1 illustrates the OARS systems engineering process (Buede 2009, Ch. 1).

The schedule of our capstone project consisted of three academic quarters of work, with a main reporting milestone at the end of each quarter (each quarter consisted of approximately three months). These milestones were the In Progress Review (IPR) #1, IPR #2, and the Final Brief. Both of the IPRs were presentations where our team briefed our current progress, findings, and path forward, to our project advisors, stakeholders, classmates, and other NPS faculty. The Final Brief was a presentation that summarized all of our work, conclusions, and recommendations. Due to the fact that our work was divided by three distinct milestones, we divided our systems engineering approach into three distinct sections, as shown in Figure 1.

The three different color shades display the specific areas of work that were to be completed or in-process by each milestone IPR. The green arrows show the feed forward requirements of the process. The blue arrows show the feedback loops in the system as the system was developed, requirements were found, and the team‟s knowledge of the subject area grew. The black diamonds displayed are the major milestone reviews that were completed at each stage of the system development. The elements of the system design were reiterated in place, to transform the piracy threat from a nebulous series of issues to a definable, model-able, and scalable solution (Maier and Rechtin 2009, Ch. 1).

1. Mission Conceptualization

The Mission Conceptualization block contained the effort to define the operational requirements for the system and to validate the feasibility of those requirements. The block consisted of the mission development, operational requirements, and feasibility analysis. The mission development was the team‟s initial work and starting point for a concept to meet the piracy threat. This was done to identify and mitigate possible team biases for the deployment of the system. Such biases included an overdependence on airship technologies, and a preference for the Broad Area

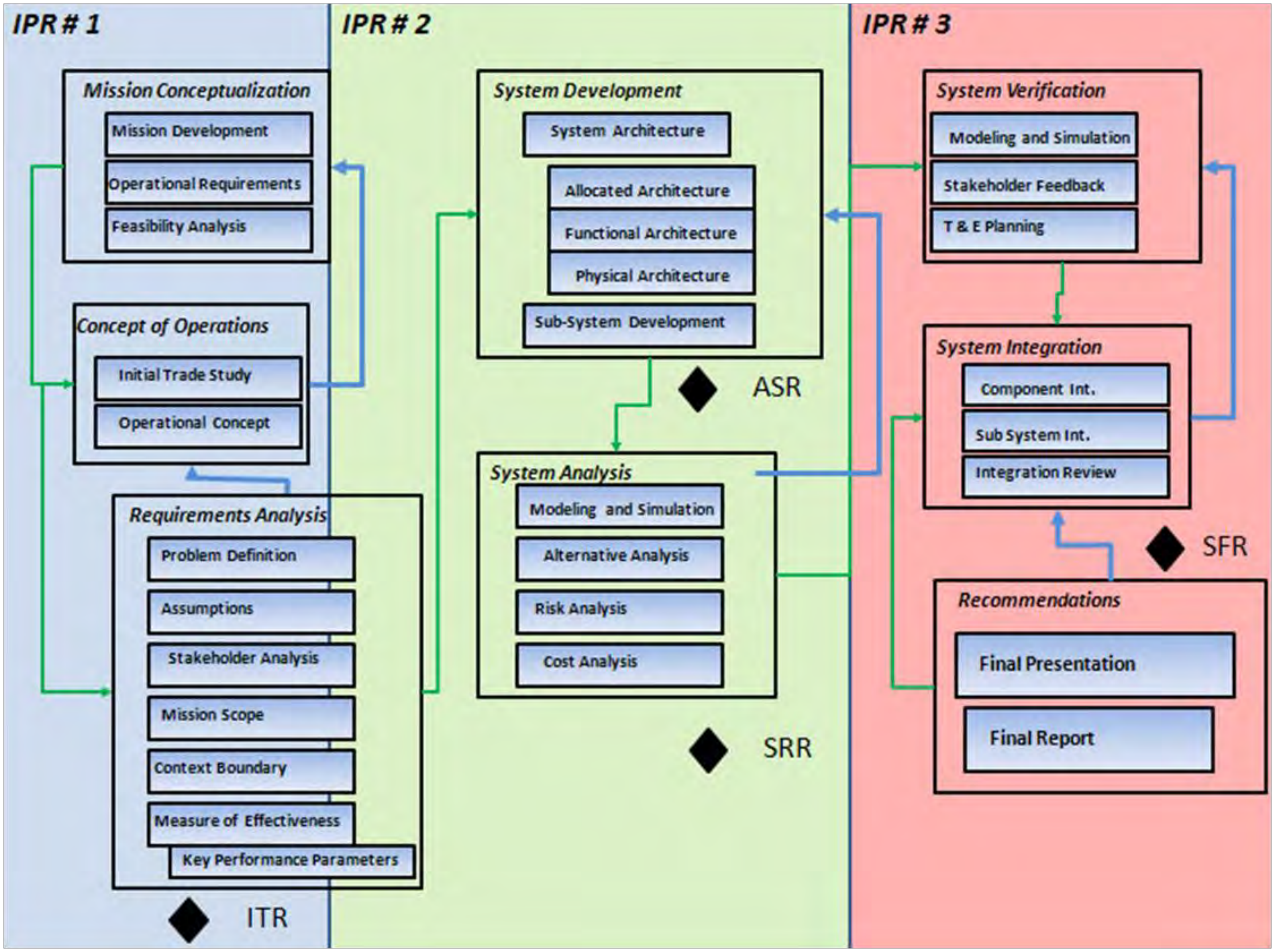

Figure 1. OARS System Engineering Process.

Maritime Surveillance (BAMS) Unmanned Aerial Support (UAS) system. The operational requirements listed the possible environments and situations the system would be expected to encounter, such as the Gulf of Aden environment. The Feasibility Analysis set the limits of the system to coincide with the timeframe, cost, and technology maturity of the possible system solution. Although this step did not finalize a list of requirements, it set the framework for the requirements analysis, and the development of the Concept of Operation (CONOPS) for the OARS system.

2. Concept of Operations

The CONOPS phase was completed concurrently with the requirements analysis, and detailed the process by which the needs and stakeholder requirements became crafted around a material solution, the idea being that the only solutions that cannot be used are the ones that are never considered. The initial trade study listed all possible solutions that could have been used to meet the mission framework and requirements. With a defined list of possible solutions, the trade study compared each by current manufacturing capabilities, technology readiness levels (TRL), and subject matter expertise. This allowed the team to narrow down the field of possible solutions. The operational concept now defined the size, scope, location, and functions of the system.

3. Requirements Analysis

The Requirements Analysis phase was an ongoing and iterative process that sought to refine the piracy problem from a nebulous series of wants and issues to a measureable, quantifiable set of mission performance parameters. This process started with a formal, stakeholder-reviewed problem definition and was bound by the assumptions needed to define the problem. A thorough stakeholder analysis listed the operators, military personnel, concurrent system representatives, and contractor support. With stakeholder feedback, a mission scope was developed to meet the problem definition.

4. System Development

The System Development phase of the SE process resulted in the creation of the OARS System Architecture. The System Architecture started to take shape as the formal CONOPS model, the objective hierarchy, and the functional hierarchy evolved.

The team conducted a House of Quality (HOQ) analysis to quantify which design characteristics were most critical to the stakeholders. The team determined that "Detect" and "Track" were the most valuable design characteristic, as indicated from the associated weighted metrics. To gauge the effectiveness of these design characteristics during OARS system modeling and design, twelve Key Performance Parameters (KPPs) were selected from a pre-determined list of Measures of Performance (MOPs). Some of these KPPs included percent of pirate detection, coverage area, intercept time, and number of engagements. These twelve KPPs became the test metrics for system comparison during the modeling and simulation phase.

After the MOPs and KPPs were defined, a functional architecture was derived to meet these objectives. With the functional architecture developed, the Functional Allocation step mapped the system‟s functions to a corresponding physical element under the CONOPS. This resulted in the physical architecture. After the allocated architecture, physical architecture, and functional architecture were finalized, the overarching system architecture for the OARS system was defined. This system architecture was then further decomposed into the sub-system components of the OARS architecture. The key stakeholders were then consulted and their feedback was implemented back into the design of the OARS system. A finalized version of the OARS concept was honed in upon, and a process and strategy for its testing and evaluation began.

5. System Analysis

The System Analysis phase consisted of initial Modeling and Simulation (M&S) efforts, risk analysis, and cost estimation calculations. Although the overarching OARS system had been refined, the elements, components, and additional solutions were compared with these processes. During this phase, the two OARS alternatives, OARS

Basic and OARS Augmented, were weighed and scored against the status quo on a basis of mission performance, feasibility, cost, and risk.

6. System Verification

The System Verification process contained robust Modeling and Simulation scenarios from which the alternatives were modeled and analyzed further. Using the two identified alternatives, OARS Basic and Augmented OARS, the team built models of each and simulated their operations using the Naval Simulation System (NSS) software. Each scenario contained the same environmental modeling parameters, which consisted of: 355 transiting cargo vessels, 100 pirate motherships, and 200 pirate skiffs. The model environments spanned 390,000 square miles of ocean in the Gulf of Aden and simulated anti-piracy operations during a 30 day period.

During the System Verification phase, the team focused on particular NSS data measurements which were relevant to original stakeholder MOEs, such as, percent of pirate detection, number of successful pirate attacks, and number of engagements.

7. System Integration

The System Integration phase of the systems engineering process defined an integration strategy for the OARS system. The team analyzed each subsystem that make up an OARS system. From there, the interoperability of each subsystem was checked against the other subsystems to determine if they could be integrated. This was done by conducting research of the subsystems and their corresponding support systems, as well as consulting with the subsystem‟s Subject Matter Experts (SME). One example of an integration concern was whether or not the host vessel could support multiple UAVs, their launch platforms, and control stations.

8. Recommendations

Finally, the Recommendations phase of the systems engineering process was where the OARS team computed all findings from the previous phases and made recommendations for the most efficient and cost effective system, as well as

recommendations for areas of further study. Based on life cycle costs and the effectiveness results from the modeling and simulation analysis, the OARS team recommended the OARS Basic alternative to be utilized in future anti-piracy missions.

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II. PROBLEM DEFINITION

Focusing on the Requirements Analysis Block of the SE design process, the OARS team adopted a multi-objective approach for defining the best system with regard to stakeholder needs. The following chapter transforms the OARS team"s stakeholder inputs and requirements analysis effort into the CONOPS that is used as the basis of the system"s design.

A. PROBLEM STATEMENT

Global piracy has progressively increased over the last four years, significantly impacting maritime commerce and burdening international maritime navies. Due to CTF-151"s efforts of patrolling the IRTC, the piracy problem has began to spread to a larger ocean environment. The problem is to comprehensively survey and protect a vast amount of ocean. Additionally, Somali pirates are hard to identify from normal fishermen, so a capability needs to exist to allow for classification of pirates before they attack.

The OARS system will attempt to deter piracy in a vast area of open ocean by providing UAV surveillance and reconnaissance. The OARS system"s UAV technology will attempt to classify pirates before they attack. Once pirates have been identified, the system should be capable of neutralizing and detaining the pirates.

B. REQUIREMENTS ANALYSIS

Requirements are generally considered the cornerstone of the systems engineering process. Originating requirements are those requirements initially established by the system stakeholders, with the help of the systems engineering team. Some examples of originating requirements for the OARS system were the requirements for capturing of live-video surveillance of pirate activity and the requirement that UAVs should not use lethal force. The systems engineering design process is a mixture of establishing requirements to define the design problem and portioning the physical resources of the system into components that perform functions that meet the requirements. Many

important decisions are made by the systems engineering team that will ultimately affect the performance of the system and the satisfaction of the stakeholders (Buede 2009).

1. Stakeholder Analysis

A stakeholder analysis was conducted to gain a better understanding of the needed capability and determine customer desires from a larger point of view, with the goal of addressing joint, international and naval service requirements.

The fundamental need was framed as the next upgrade using a system approach to a piracy suppression mission. The team conducted stakeholder analysis to create a list of needs and desires from an emerging list of stakeholders. Information was gathered by conducting interviews via email, phone calls and telephone conferencing. The questions were designed to guide the stakeholder through the difficult issues the OARS team discovered during their research. Follow-on discussions were teleconferenced with willing stakeholders who offered time to discuss their needs, requirements and concerns regarding an OARS System.

The OARS team was initially evaluating the use of lethal deterrence aboard the UAVs, but the results of the stakeholder analysis indicated that this was a bad idea as it would not comply with international maritime law. For this reason, the UAVs were only used for surveillance and reconnaissance.

a. Stakeholders

The stakeholders who had a vested interest were identified from the following groups of policy and decision-makers: Fleet Commands, users, acquisition agents, developers, engineering contractors and Test and Evaluation (T&E) analysts. The key stakeholders for this undertaking were determined to include, but are not limited to the following:

Table 2. Primary Stakeholders.

Stakeholder Category	Organization	Name	Title/Role
DoD/U.S.	United States Navy	CAPT Richard Brown	Executive Assistant to the Assistant Secretary of the Navy
	United States Navy	LT David Cook	Riverine Squadron Three
	Naval Postgraduate School	David Place, CAPT USN Retired	UAS Fleet Liaison
International/ Joint	International Crime Service Maritime Bureau	Cyrus Moody	Manager
UAV Industry	Ohio Airships	Robert Rist	Engineer
	Airship Consultant	Joe Bloggs	Consultant
	Hawker Beechcraft	Tim Schow	Engineer
	Tomorrow Aerospace	Shobhit Mehrotra	Lead Structural and Control Engineer
	Aereon Corporation	William McE. Miller	President and CEO
	NRL Monterey, CA	Dr. James Hansen	PARS SME

b. Fleet Commands

The Fifth Fleet has an interest in developing a solution to the hostile actions of pirates directed at shipping placed under their protection. Their involvement with the SE process was the most influential due to the sponsor-like relationship fleet commands have with sponsor funding.

c. User Representatives

The naval vessels engaged with CTF-151 operations have been operating for two to three years. A Naval Ship Commanding Officer who commanded the USS Gettysburg during one assignment to this region provided invaluable points of view on a variety of issues related to user operations, such as the boarding of pirate mothership and the capturing of prisoners.

A Fast Boat Commanding Officer (CO) with responsibilities to develop tactics for preventing hostile boardings and attacks upon commercial vessels in the

western Arabian Sea and Gulf of Aden provided critical resources to OARS. One point that he made very clear was that the early identification of pirates was very important as it made the boarding party much safer. This Commanding Officer had developed, trained, and provided logistic planning requirements that enabled inbound naval forces to field combat-ready forces.

Additional stakeholder input was provided to our project by the Director of the Pirate Attack Risk Surface (PARS) effort at the Naval Research Lab located in Monterey, CA. The PARS Software is a predictive model that utilizes algorithms to try and predict the likelihood of an attack by pirates. Due to its classification, actual PARS data was not used in our Modeling and Simulation efforts.

d. System Developers

A number of UAV industry contacts were helpful and interested in the OARS effort. These stakeholders included companies such as Ohio Airships Incorporated (Akron, OH), Airship Consultant (Shortstown, Bedfordshire, England), Hawker Beechcraft Corporation (Witchita, Kansas), and Aereon Corporation (Princeton, New Jersey). These experienced contractors provided inputs for the interface design and communication strategy. One of the areas that they aided us in was how to operate multiple UAVs from a single host vessel.

2. Stakeholder Feedback

Stakeholder solicitation was accomplished by conducting surveys and interviews with our stakeholders, as well as researching the current solution and difficulties experienced in anti-piracy operations. Questions were designed to facilitate effective telephone interviews with stakeholders. The problem statement was formed from the inputs gathered from all stakeholder groups. A summary of key stakeholder inputs can be found in Appendix A.

a. Policy Makers' Recommendations

Research of operations policy documents offered insight into the operational capability of maritime patrolling. Based in Manama, Bahrain, the Fifth Fleet approved and funded the current CTF-151 efforts, which are limited to the oceanic choke-points in the Gulf of Aden where pirate activities had been reported and observed. The policy guidance for the maritime effort demanded a system traceable back to the following naval capability requirements:

- Forces will use multi-channel two-way C2/SA systems that protect data at the confidential or higher level of classification. All devices operated at this level that transmit and receive voice and video data will be designed to protect this data to a level merited by classified information.
- Data collected from the UAV systems will allow the dual use of UHF and Satellite distribution networks to provide un-interrupted delivery of real-time information for on-scene commanders to conduct multi-sensor patrols. These patrols will conduct around the clock in all weather conditions to allow maximum probability of hostile detection within the operational area assigned.
- Blue Force support vessels will provide additional afloat services as required to conduct internationally supported INTERPOL certificated activities. UAV units operating in an operation space will employ capabilities that allow assets to deploy and retrieve on a host vessel for the purpose of refueling and servicing multiple detection and data transmission equipment.
- Blue Force Commanders will provide necessary direction to Multi-system operations in a coordinated manner with one Common Operational Picture (COP).

b. Acquisition Agent Recommendations

Interview responses from acquisition community members offered understanding about the early-milestone preferences of today‟s acquisition workforce. The following were recommendations from the acquisition agents:

- Develop an Initial Capability Document (ICD) for OARS.
- Create a formal Program Objective Memorandum (POM) initiative for OARS.
- Continue dialogue with the operational forces to identify evolving needs.
- Continue socializing the concept to U. S. Navy leadership.

- Develop Capability Development Documents (CDDs) to identify the highest priority required capabilities as determined by the warfighter input.

c. Clients and Users Recommendations

Interview responses from the user community offered insight to the preferences of today‟s solution, and provided feedback on additional capabilities desired by the end-user. The current force capability fielded has communication systems (secure and clear), recording devices for evidence collection, command and coordination chain of command, and gun weapon systems (major and minor caliber). Some foreign ships have medium caliber guns.

The following desired capabilities were identified by the users:

- Tracking of suspicious shipping in transit channels where Blue Cargo vessels pass.
- Situational awareness of Blue Forces in the transit channels.
- Communication connection to the OARS command center.
- Secure and unsecure communications.
- Logistical support plan.
- Data sharing to support the COP.
- Interoperability between coalition, service elements, and other agencies for joint missions.
- Ruggedized equipment with enhanced durability for the different operational environments experienced.
- Ease of use and ergonomics for primary search sensors.

7. Needs Analysis

The results of the OARS team‟s research and interviews with key stakeholders enabled the requirements development to progress with a rich data set. However an independent detail analysis of the problem was needed to further constrain and define the problem. Every pirate attack that occurred in the Gulf of Aden during 2010 and the first quarter of 2011 was recorded by the ICC Piracy and Robberies report. The team cataloged and analyzed this data to further define the piracy problem and develop the

performance parameters of the system. Figure 2 shows the highlights of the team"s data analysis. The team derived values for the 50th percentile and the maximum percentile for metrics such as; distances between pirate attacks, hours between pirate attacks, speed of attacks, and areas covered by the pirates. The chart illustrates the values of the distance between attacks and hours between attacks. It then compares the operating range between these attacks. The team assumed the effect to be linear and this led to the range, endurance, and area covered metrics. The metrics were derived to cover the majority of attacks in an area of 1.1 square million miles. The pie chart that is located in the lower left corner of Figure 2 shows the type of attacks the pirates have committed. It shows that all attacks occur when ships are underway. The last chart shows the number of attacks per season, and illustrates that the attacks are dependent on weather and sea state.

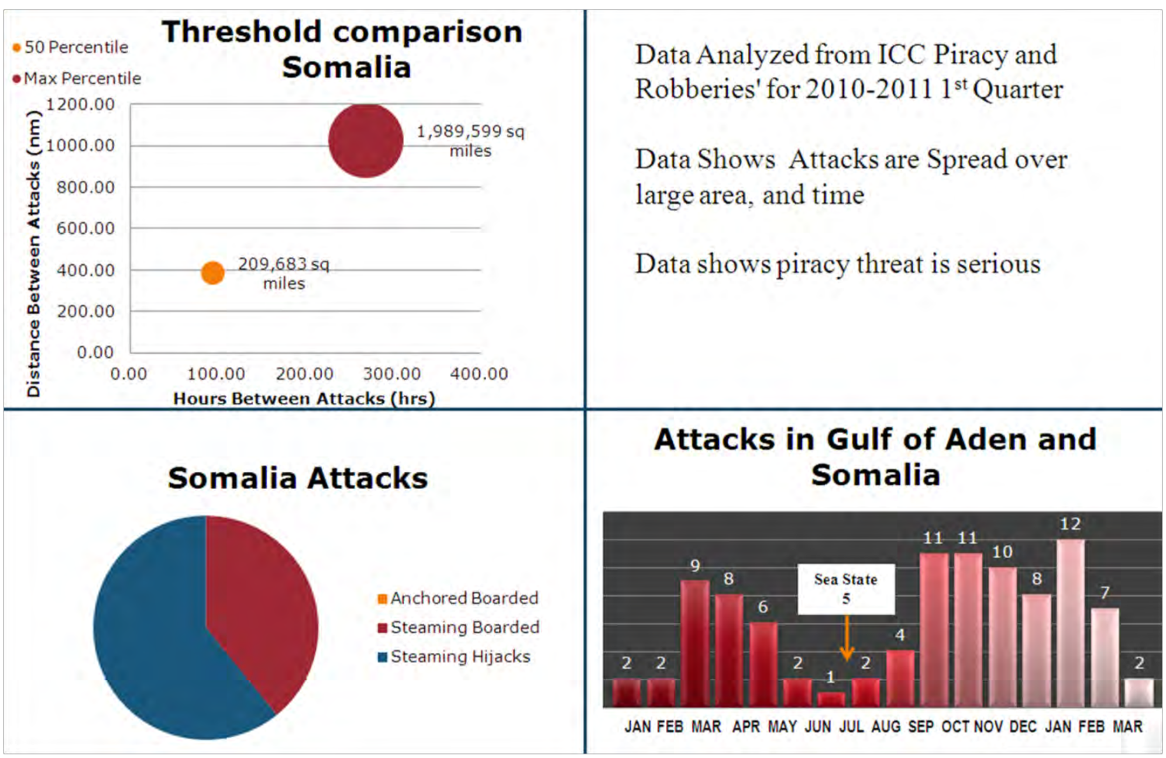

Figure 2. OARS Affinity Diagram.

8. Effective Needs Statement

Discussions with stakeholders allowed the team to formulize a chain of events that must be followed by the OARS system in order to effectively counter piracy. It was identified that the first action that must occur is the "detection" of pirates. Once detected, the OARS system must maintain "tracking" of those pirates. The OARS system must then be able to "intercept" the pirates. And finally, the OARS system must be able to "neutralize" the pirates by disarming them and making arrests. The team also made the decision that this system would be designed to be as cost effective as possible. And do to the fact that the system will be operating in International waters, the system must also comply with International Maritime Law.

Following a full examination of stakeholder requirements, the results of the needs analysis, and the OARS team"s original assumptions that were documented in Section C of Chapter I, the following effective needs statement was derived:

> *The OARS system will economically and efficiently detect, track, intercept, and neutralize pirate threats across 1.1 million square miles of open ocean, within compliance with international maritime law.*

9. Input-Output Model

In Figure 3 the OARS team developed a simple view of the inputs and outputs of the system at the top system level. This view provides a partial list of controllable and uncontrollable inputs and their respective outputs after the system while operating. This list was not all inclusive but is a partially focused set of considerations based on the existing CTF-151 system used today and considered essential for operations.

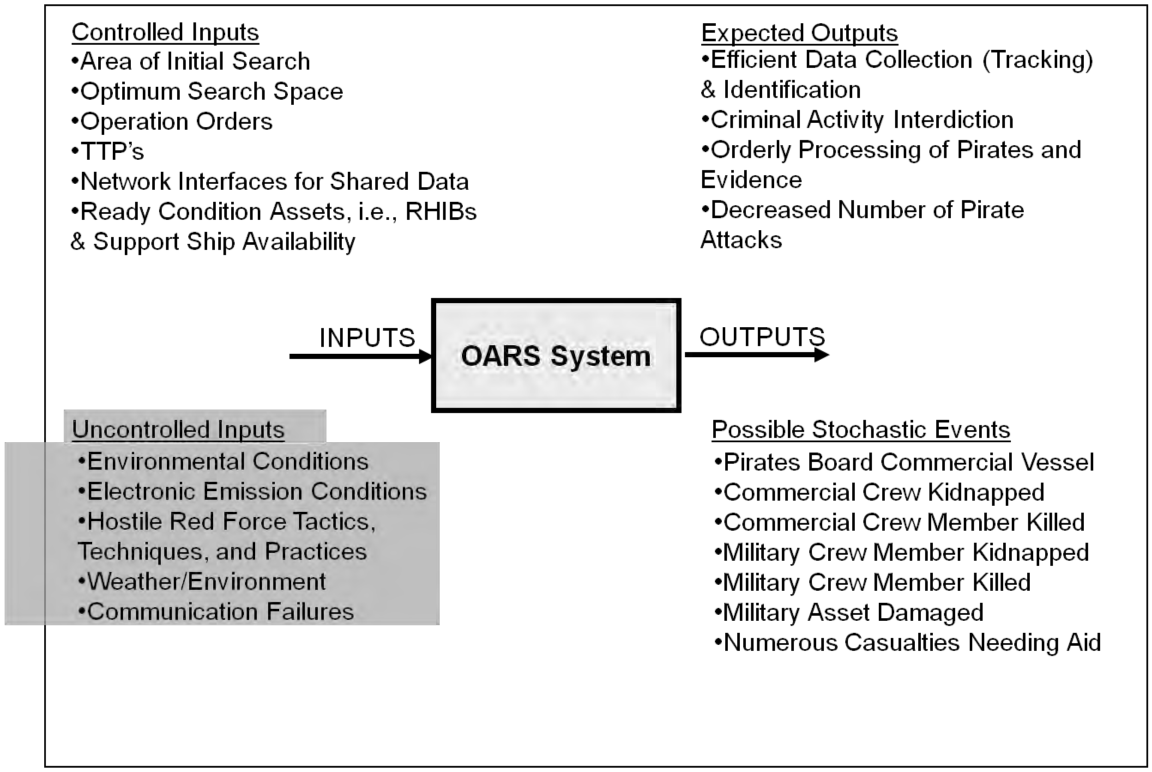

Figure 3. OARS Input/Output Model

a. Controllable Inputs:

The operators have the ability to select one operating area in the most probable intercept position. The random probability of the hostile intrusion was modeled through the Naval Simulation System (NSS) software to forge the environment of space and time attached to the goal of response and prevention of boarding.

The material requirements were in the form of seagoing systems deployed now for monitoring events at sea in an area of interest by U. S. Naval forces in keeping with common operating Tactics, Techniques and Procedures (TTPs). The physical boundaries of the system were supported with common maintenance approaches used by deployed units.

Data sets with formatted descriptive elements, such as Operational Orders, were provided via common secure communications and issued by appropriate Blue Force Commanders. Risk mitigation plans and procedures were pre-planned to accommodate hazards and eventualities that were considered to challenge the integrity of primary

mission objectives. For the purposes of this project, it was assumed that these C2/SA devices will interface with a network capable radio/transmission device.

Additional information systems relying on an available network capable system did include automated Weapons Systems Status, Individual Health Monitoring, and other systems reporting details relevant to the operating environment. Inputs were processed via networking interfaces like Universal Serial Bus (USB), Ethernet, and Serial ports.

b. Uncontrollable Inputs:

With all operational systems, the uncontrollable inputs consisted of networking anomalies, environmentally destructive effects, electromagnetic effects, and equipment failures. Our SE process considered a variety of opportunities to create harmful eventualities during operations, in hopes of designing so as to mitigate or prevent failure events.

c. Controllable Outputs:

Outputs were enabled via networking interfaces. As a result of timely communications and detection processes, the ability to develop and analyze data in a patrolling at-sea environment allowed naval assets to search, detect, track, and target contacts with a variety of on-vessel controlled sensors. Actionable information through visual images of ships and activities at sea in daylight and low light level periods were viewed and shared with a command and control center. The data sent from the system to a shared network provided the best picture of situational awareness that was possible under the mechanical, electrical and stochastic conditions. The system provided services in response to developed situations that demanded specialized resources like weapon systems on RHIBs and medical services following the use of lethal force. Additional services like detention and transportation of criminal suspects, seized property, and contraband were provided.

d. *Uncontrollable Outputs:*

Some of the uncontrollable outputs that can have a negative effect on shipboard operations were identified as; cross-talking circuits, network interruptions, garbled or unreadable data, and other data elements. The system was able to overcome these obstacles through redundancy and sound communication procedures. The failed processing of data allows corrupted data to be considered as actionable data necessary to be placed in context and used appropriately despite error and inconsistency. The system was robust enough that such weakness in command and control offered opportunity to dismiss unreliable data.

The IO model in Figure 3 provided the SE Team another tool that described the basic information flow of data and the basic functions expected within the communications /networks/weapons system at the top level. In other words, the team used the IO model to determine, "What does the system need to do?" rather than try to resolve „How does the system do it?‟ The description of the system then allowed the team to move forward into the functional analysis.

C. CONCEPT OF OPERATIONS (CONOPS)

1. Current Anti-Piracy Operations (CTF-151)

Current anti-piracy operations consist of Combined Task Force 151 (CTF-151) operating in the Gulf of Aden and the surrounding area. CTF-151 is comprised of a mix of U.S. Navy ships and coalition ships commanded by a rotating command post. The ships are assigned individual patrol areas that patrol the entire region on a twenty-four hour basis. Ships are assigned individual patrol regions which are designed to maximize the amount of area covered based on current information on suspected pirate activity. When a distress call is received, the nearest CTF-151 ship responds. When the U.S. Navy or coalition ship is within acceptable helicopter range, a helicopter is deployed to provide immediate assistance to the merchant vessel. At that time, the helicopter may also start to gather on-site intelligence, which is then relayed back to the commander on board the ship. The helicopter is not allowed to automatically engage the suspected pirates unless in self-defense. Helicopters are allowed to use intimidation tactics to deter

suspected pirates. If suspected pirates do not stop, the attack helicopter pilots are allowed to ask commanders for a "weapons free" order which allows them to utilize the small caliber machine guns to fire in front of or behind the suspected pirates for further intimidation tactics. When suspected pirates have stopped, RHIBs are deployed from the ship to capture prisoners and evidence for eventual prosecution. RHIB boats are lightly manned and equipped with personal small arms, although they are only utilized for self-defense purposes. Figure 4 shows an Operational Concept diagram of the CTF-151 solution. Since CTF-151 is comprised of many different vessels from many different countries, its Operational Concept includes a plethora of naval vessels. The concept diagram depicts all elements involved in a CTF-151 mission including naval vessels, helicopters, container ships, RHIBs, and satellite communications. The background of the diagram is a depiction of the Gulf of Aden and Indian Ocean with markers indicating where acts of piracy occurred in 2010.

Figure 4. Operational Concept: Current Solution, CTF-151.

Some ships that are not equipped with a helicopter may employ an UAV that performs reconnaissance missions on suspected pirates. Suspected pirate motherships are difficult to distinguish from ordinary harmless fishing vessels and vessels containing people and arms with the intent of capturing unarmed merchant vessels. The UAV provides real-time, up-close, video surveillance of the suspected pirates.

2. OARS CONOPS Generation

The requirements analysis phase of the systems engineering process led the OARS team to develop multiple alternative systems. The stakeholders were very clear on the needs of the OARS anti-piracy system. These needs were focused around the particular need for a system that could cover a broad area of ocean, due to the fact that Somali Pirates are expanding their reach into the Indian Ocean and beyond. For this reason, the OARS team sought to create a system that utilized unmanned aerial vehicles (UAV) that would be launched from "host vessels" at sea.

The purpose of the host vessel is to provide a resource from which to launch, recover and support the UAVs. The area of operation about the host vessel will be defined by the most effective and efficient use of a number of UAV craft to provide assistance to all vessels in peril within a reasonable time period. The sensors will detect and communicate video and location data such that critical tracking will have occurred in determining the identification of a target of interest.

The elements of the OARS system are: Host vessel, UAVs, helicopters, satellite networks, pursuit vessels, and targets. The OARS system has a fixed number of UAVs that perform detection, surveillance, tracking, identification, and communication of data. These UAVs have been proven to operate well in all expected weather conditions. The winds are generally below 17 knots and gale winds develop in the more eastern oceanic areas from the Horn of Africa up to 40 knots. The temperatures were generally hot year-round with temperatures routinely exceeding 90 degrees.

a. *Basic OARS*

The OARS Basic CONOPS model includes a ship capable of supporting multiple swarms of UAV operations, armed helicopter operations, all net-centric C4I requirements, brig capabilities for transportation of captured pirates, as well as weapons for self-defense. Pursuit vessels are also required to capture pirates once they have been detected. Figure 5 represents an Operational Concept diagram for OARS Basic. The green radar circles represent individual search area range.

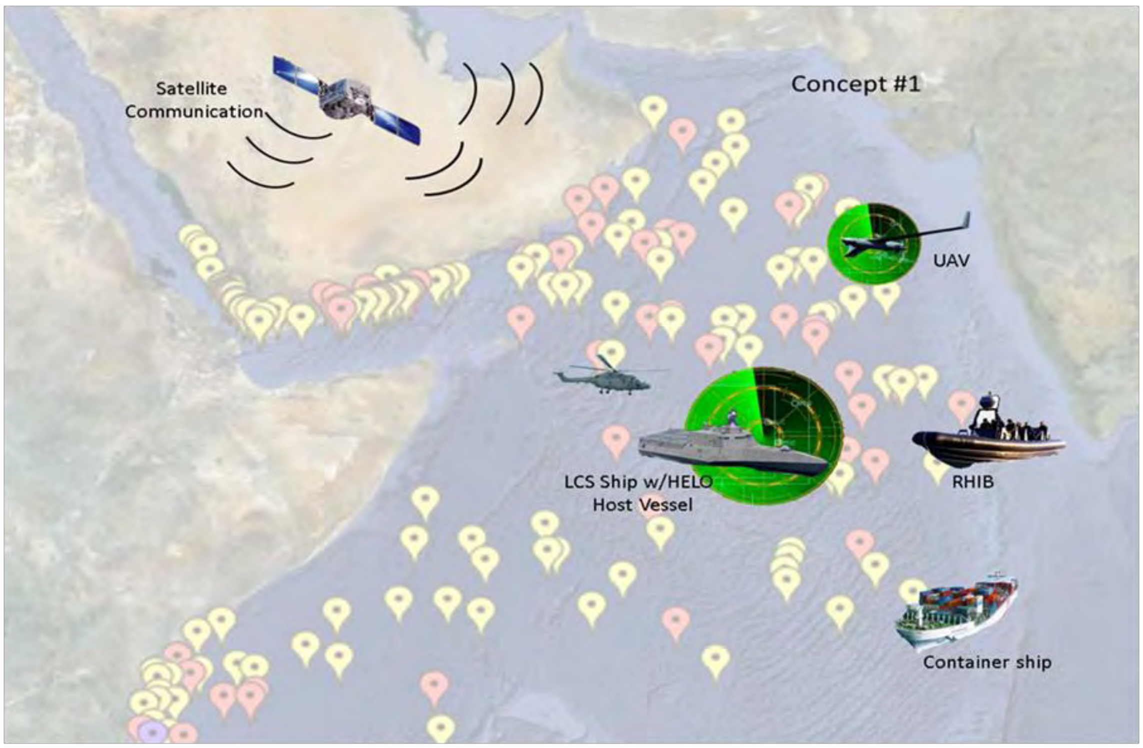

Figure 5. Operational Concept: OARS Basic.

As mentioned in Chapter 1 of this report, the OARS team focused on protecting the entire Gulf of Aden from piracy. For this reason, six individual OARS Basic systems will be strategically placed in the Gulf of Aden. Figure 6 illustrates the area of coverage that would be achieved by six Basic OARS systems.

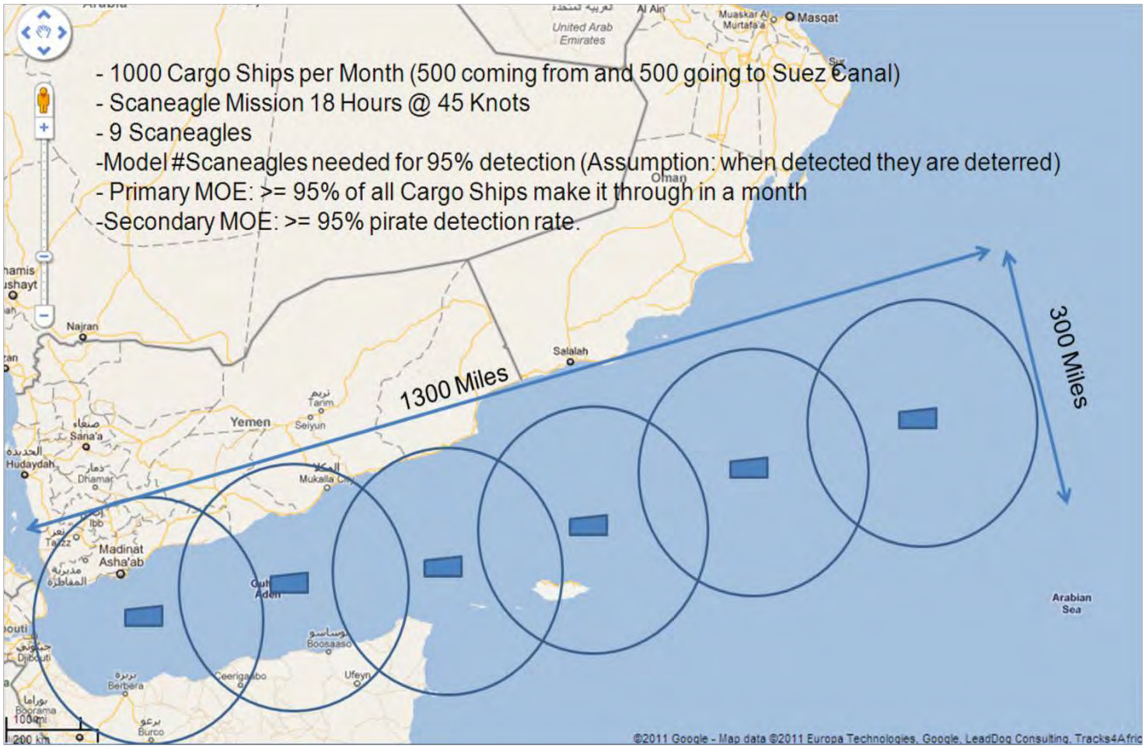

Figure 6. Six OARS Basic Systems Placed Within the Gulf of Aden.

b. Augmented OARS

The last CONOPS option includes everything from the Basic OARS model, plus an augmentation using a high altitude long range airship such as the Broad Area Maritime Surveillance (BAMS) UAV. This will supplement the coverage area provided by the Basic OARS model which uses much slower ship-launched UAVs. The BAMS UAVs will be land-based and located wherever the OARS commander deems necessary based to the perceived threat. The Augmented OARS Operational Concept diagram is shown in Figure 7.

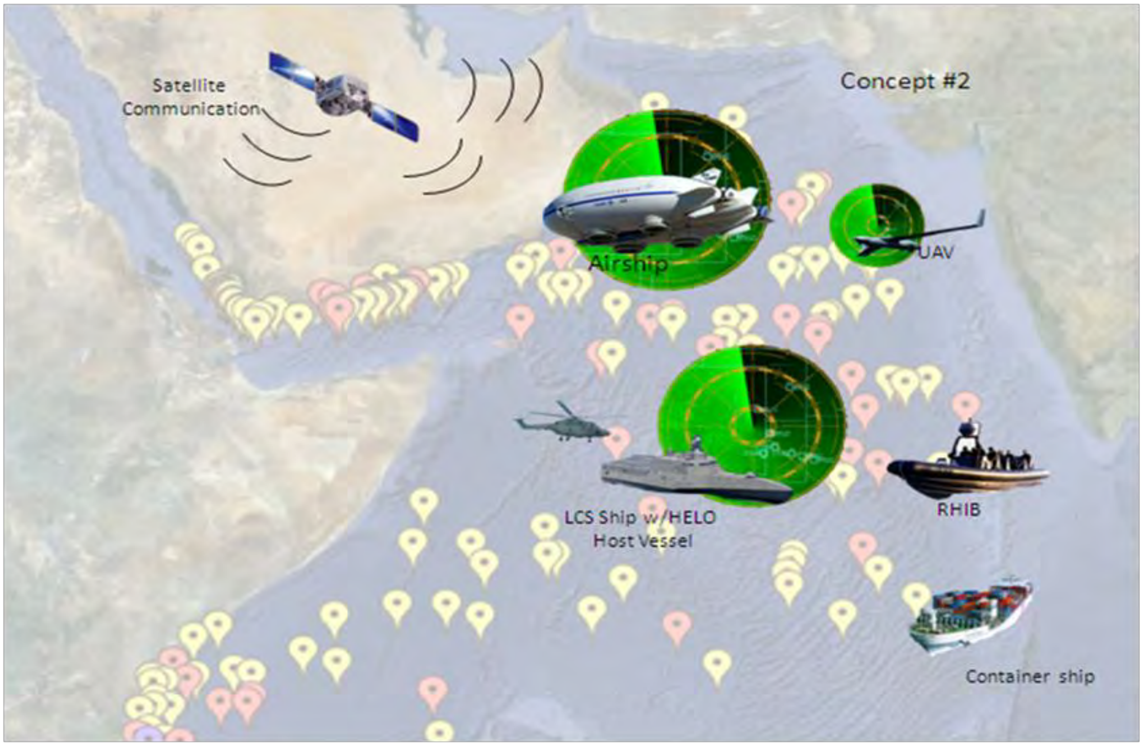

Figure 7. Operational Concept: OARS Augmented.

Just as with the Basic OARS CONOPS, the Augmented OARS CONOPS will also feature six identical OARS systems to allow for complete coverage of the Gulf of Aden transit corridors. Figure 8 illustrates the area of coverage that would be achieved by utilizing six Augmented OARS Systems in the Gulf of Aden. The large oval-shaped area that is colored "green" on the figure illustrates the added search pattern that would be gained from the BAMS UAV or Airship.

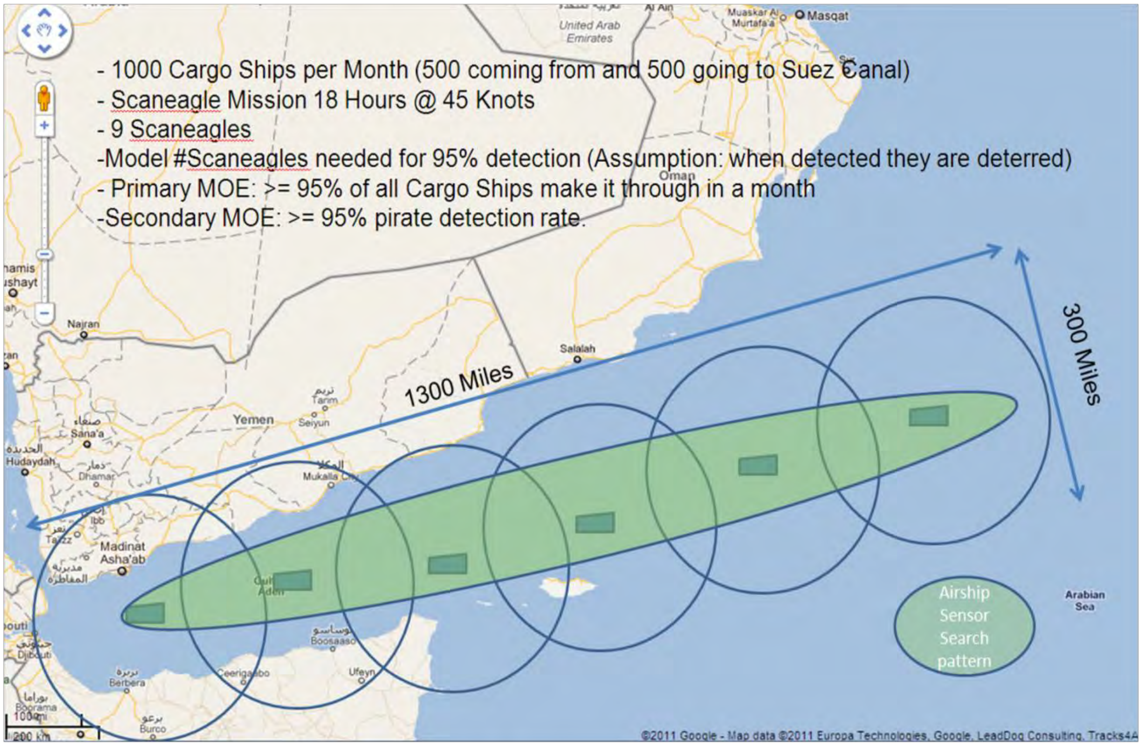

Figure 8. Six Augmented OARS Systems Placed Within the Gulf of Aden.

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III. DESIGN

The Design and Analysis of the OARS system provides a solution space for the problem definition, primitive needs, refined requirements, and stakeholder‟s interest. It combines elements of the Requirements Analysis, System Development, and System Analysis stage of the System Engineering process. It also helps to develop the inputs and alternatives for the modeling and simulation needed for the final result. The Design and Analysis stage begins with the system requirements and refines the customer needs through the House of Quality (HOQ). It maps the requirements through the functional analysis into a possible architecture. With the elements of the architecture known, sub-system alternatives are generated and screened by feasibility. It then details recommended alternatives for the modeling and simulation (Blanchard and Fabrycky 2006, Ch. 2 and 3).

A. SYSTEM REQUIREMENTS

The system requirements are the actions and processes that the OARS system is to complete, which are usually articulated in "shall" statements. They are divided into two separate groups, functional and non-functional requirements. The Functional Requirements are the requirements that the OARS system is to complete by performing the functions and actions necessary to solve the problem definition and mitigate pirate threats within its context boundary. The Non-functional requirements are those requirements that support the completion of the functional requirements. These included the suitability requirements, such as reliability, maintainability, and usability.

1. Functional Requirements

The functional requirements are the actions and functions that the OARS system must carry out to deter piracy and protect shipping in its area of operation. As defined by the effective needs statement, the OARS system must detect, track, intercept, and neutralize threats within compliance of maritime law. In order to accomplish this, the OARS system must carry out a mission defined by the mission‟s functions. These

mission functions are to start a mission, patrol an area, communicate, engage hostiles if detected, and finally, to return to port when the mission is complete. These functions are illustrated in Figure 9.

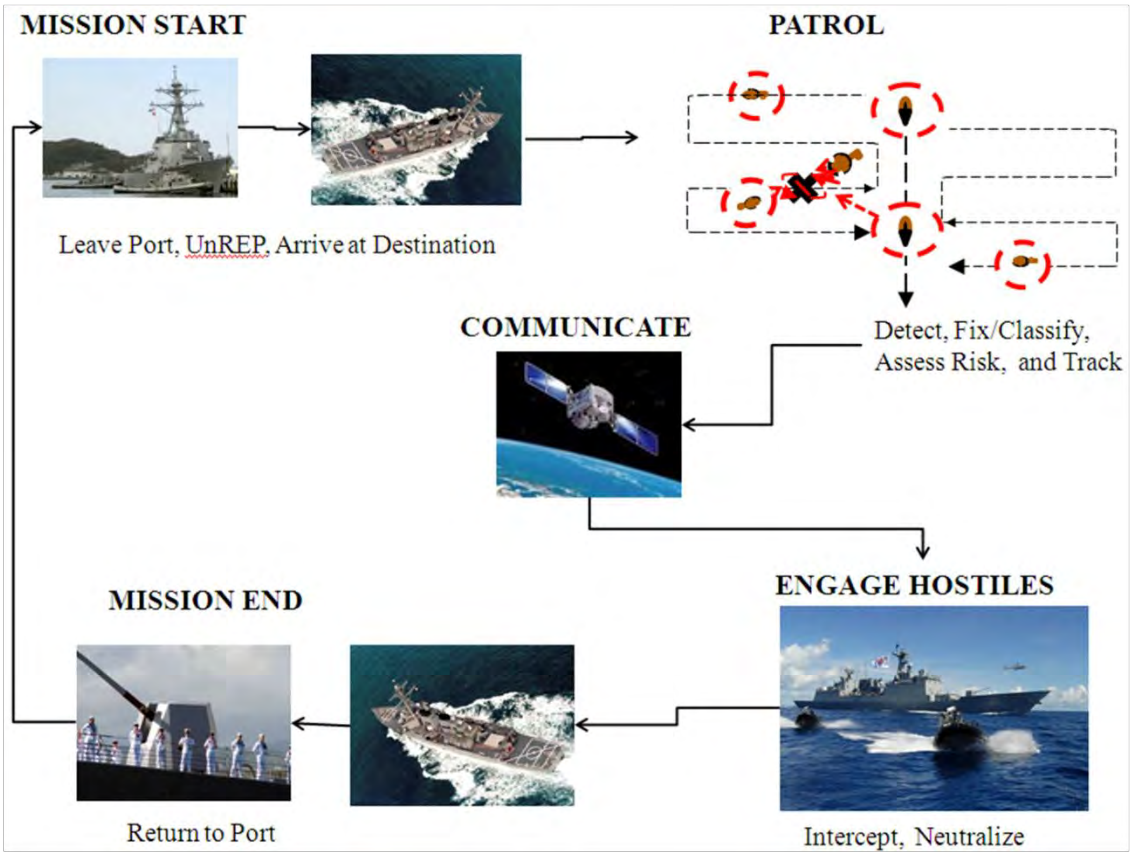


Figure 9. OARS Mission Profile.

Each of these mission functional requirements are needed to complete an OARS mission. The team created these mission functions to simplify the OARS mission profile, while still keeping in mind the needs of the OARS system. Table 3 shows how the needs statement, which was derived in Chapter II, correlates to the OARS mission profile.

Table 3. Needs Statement Mapping to Mission Functions.

Need Statement Functions	Mission Start	Patrol	Communicate	Engage Hostiles	Mission End
Detect	X	X	X		
Track	X	X	X		
Intercept		X	X	X	
Neutralize			X	X	
Within Compliance	X	X	X	X	X

The Mission Start function detailed all aspects of preparation, logistics, and movement to place the OARS system in the theater of operation. The Patrol aspect of the mission included the actions required to patrol an area of suspected pirate activity, including the Detect, Track, and Intercept functions. The Communicate function encompasses all communication efforts between the OARS system and allied vessels, friendly cargo vessels, UAVs, etc. On encounter with a group of pirates, the Engage Hostile requirement included all of the requirements needed to intercept and neutralize hostile targets. Once the mission has been completed, the Mission End aspect covered all the actions needed to return the assets and personnel to their home stations and prepare the physical systems for the next deployment required to fulfill the functions previously stated. These top level functions were developed to meet the objective requirements and were traced down to the performance parameters needed to carry out the mission.

2. Non-Functional Requirements

The Non-Functional Requirements are all the requirements necessary for continued operations of the OARS system as it carries out its mission. Non-functional requirements are the mission critical requirements that cannot be deduced from direct examination of the piracy threat but are inherent in the system. For example, the

reliability of the system helps to determine the operational availability of the sub-systems. This also helps to determine the required number of critical spares and the number of OARS systems that are actually needed. The Human Factors requirement of the system determines the operational man power requirements and determines the crew sizing per each OARS system. These non-functional requirements are typically found using “bottom-up analysis” techniques, which are techniques of tracing the requirements backwards after the system has been developed. Because the OARS team focused on UAV technology in the deterrence of piracy, the non-functional requirements were addressed briefly by the team in a top-level analysis, leaving these particular requirements as an area for future research.

B. OBJECTIVE REQUIREMENTS

1. Measures of Effectiveness (MOE)

The objective requirements, which consist of Detect, Track, Intercept, Neutralize, and Compliance with international maritime law, are broken down into function layers and are ultimately transformed into the system‟s physical architecture. The customer needs are based on a modified kill chain used by U.S. Military forces. The top-level of the OARS system included Detect, Track, Intercept, Neutralize, and Comply with international maritime law. The Detect stage was critical since this has been a continuing problem in anti-piracy operations. Often it is not until the pirates have engaged a neutral target that they are even considered suspicious. Once a possible pirate target has been found, the OARS system had to track the target to determine its course and its intention. The stakeholders have stated that finding sufficient evidence to prosecute the pirates remains a high priority for the system.

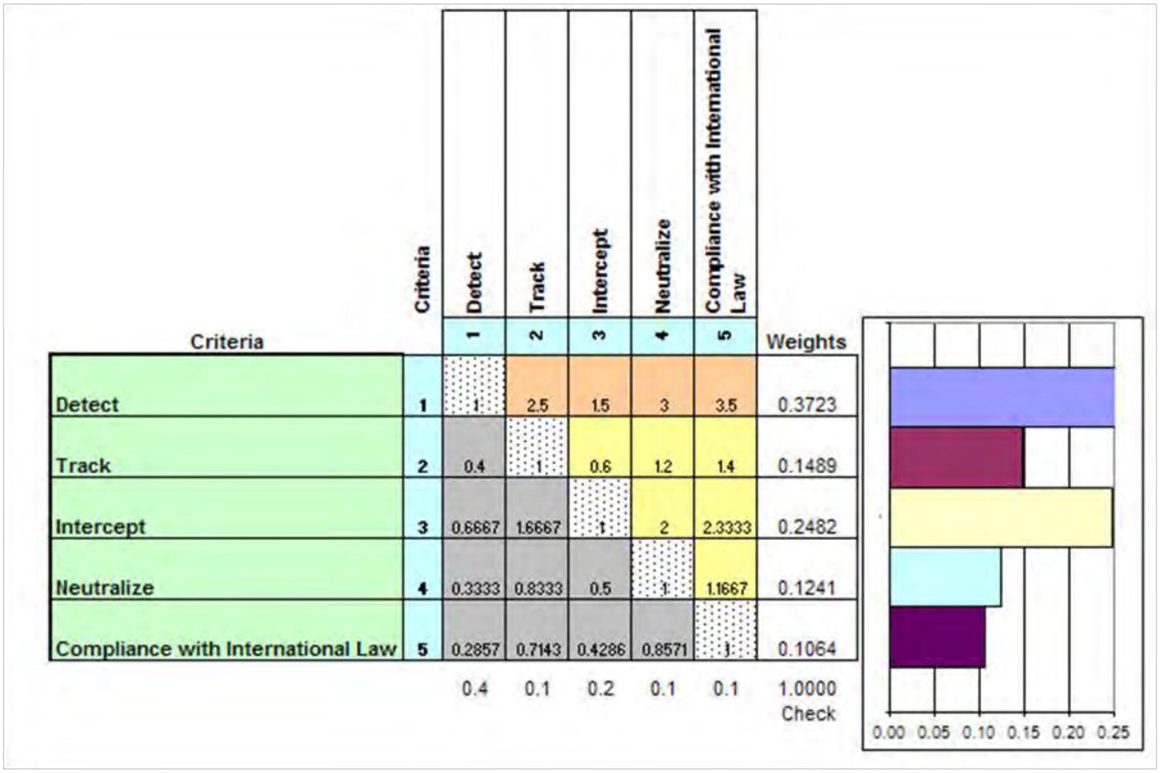
The next function of the OARS system was to intercept, or cause interception of the threat. This will force the adversary to reconsider their actions or ultimately be arrested. The last function was to neutralize the pirate threats. This could be accomplished through detaining the pirates, showing force, or the actual use of this force. All the functions must be conducted within the scope of maritime law, within the boundaries of a basic regard for the human rights of the pirates, as well as the norms and

regulations found in the Geneva Convention and the Uniform Code of Military Justice. Below these five top-level functional requirements, the detailed functions of the system fully define the mission and what actions need to take place to fulfill it. The customer‟s needs are mapped to the objective requirements. These are then met by the functions of the systems, which are mapped to the physical architecture and computed into a measureable aspect by the Measures of Effectiveness (MOE). The MOEs are then derived from a physical metric by the performance parameters. To meet the performance parameters, the derived requirements are found to determine the physical needs and requirements of the system. Since the OARS Capstone project was a top-level effort, the derived requirements from the performance parameters were not calculated.

To ensure that the requirements flow-down was within line with stakeholder expectations and to make sure that the key requirements were properly weighted, an Analytic Hierarchy Process (AHP) was used to assign customer preference to the appropriate functions. This was the start of the Quality Function Deployment (QFD) Analysis (Buede 2009, Ch. 6).

C. QUALITY FUNCTION DEPLOYMENT (QFD)

The QFD aids the stakeholder in assuring that the most critical requirement receives the greatest consideration. Design is a balance of compromises between competing goals. QFD assures that the stakeholder‟s goals and the system‟s strengths are aligned. The first step is to weigh the stakeholder‟s needs against one another in order to highlight the greatest needs. The OARS mission statement is to economically and efficiently detect, track, intercept and neutralize pirate threats across 1.1 million square miles of Open Ocean, within compliance with International Maritime Law. Each of these needs are dependent upon each other and critical to the mission statement. Figure 10 shows which mission aspects were most critical in the eyes of the stakeholders. The strongest relationship among the needs of the OARS system was the relationship between Detect and Intercept (Blanchard and Fabrycky 2006, Ch. 3).



Criteria	Criteria	1 Detect	2 Track	3 Intercept	4 Neutralize	5 Compliance with International Law	Weights
Detect	1	1	2.5	1.5	3	3.5	0.3723
Track	2	0.4	1	0.6	1.2	1.4	0.1489
Intercept	3	0.6667	1.6667	1	2	2.3333	0.2482
Neutralize	4	0.3333	0.8333	0.5	1	1.1667	0.1241
Compliance with International Law	5	0.2857	0.7143	0.4286	0.8571	1	0.1064
		0.4	0.1	0.2	0.1	0.1	1.0000 Check

Figure 10. Preference Weights of the Stakeholder‟s Needs.

The QFD process was implemented through a series of interconnecting HOQ matrices. This portion of the process begins by listing the customer needs down the left side of a matrix, as shown in the left-most rows of the AHP in Figure 11. After the customer‟s needs were listed, their corresponding rankings are then listed in the next column to the right. These rows are collectively referred to as the WHATS of the HOQ. The columns are the technical response of the designer and are commonly referred to as the HOWS of the HOQ. The HOWS are the functions for the OARS system.

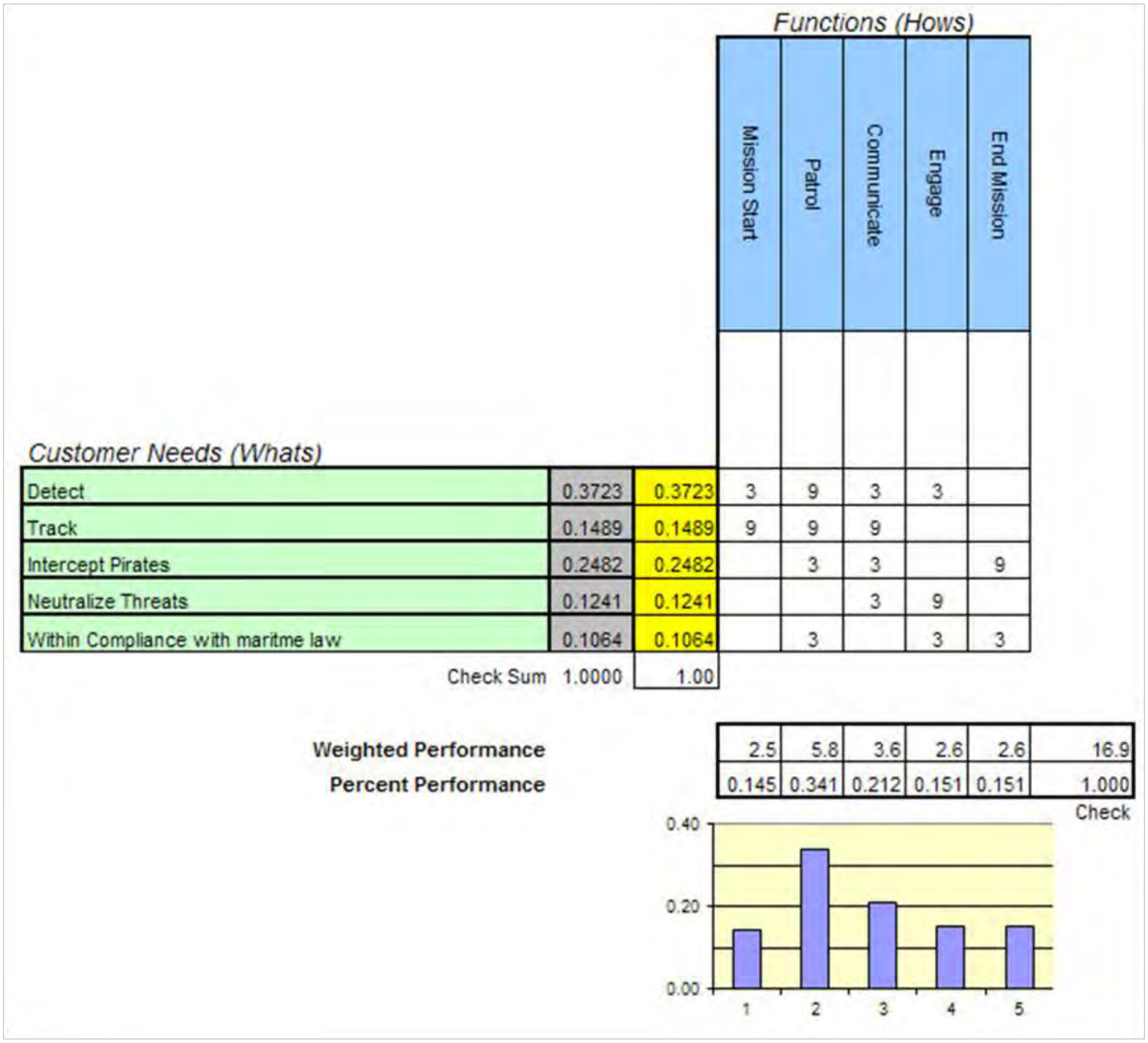
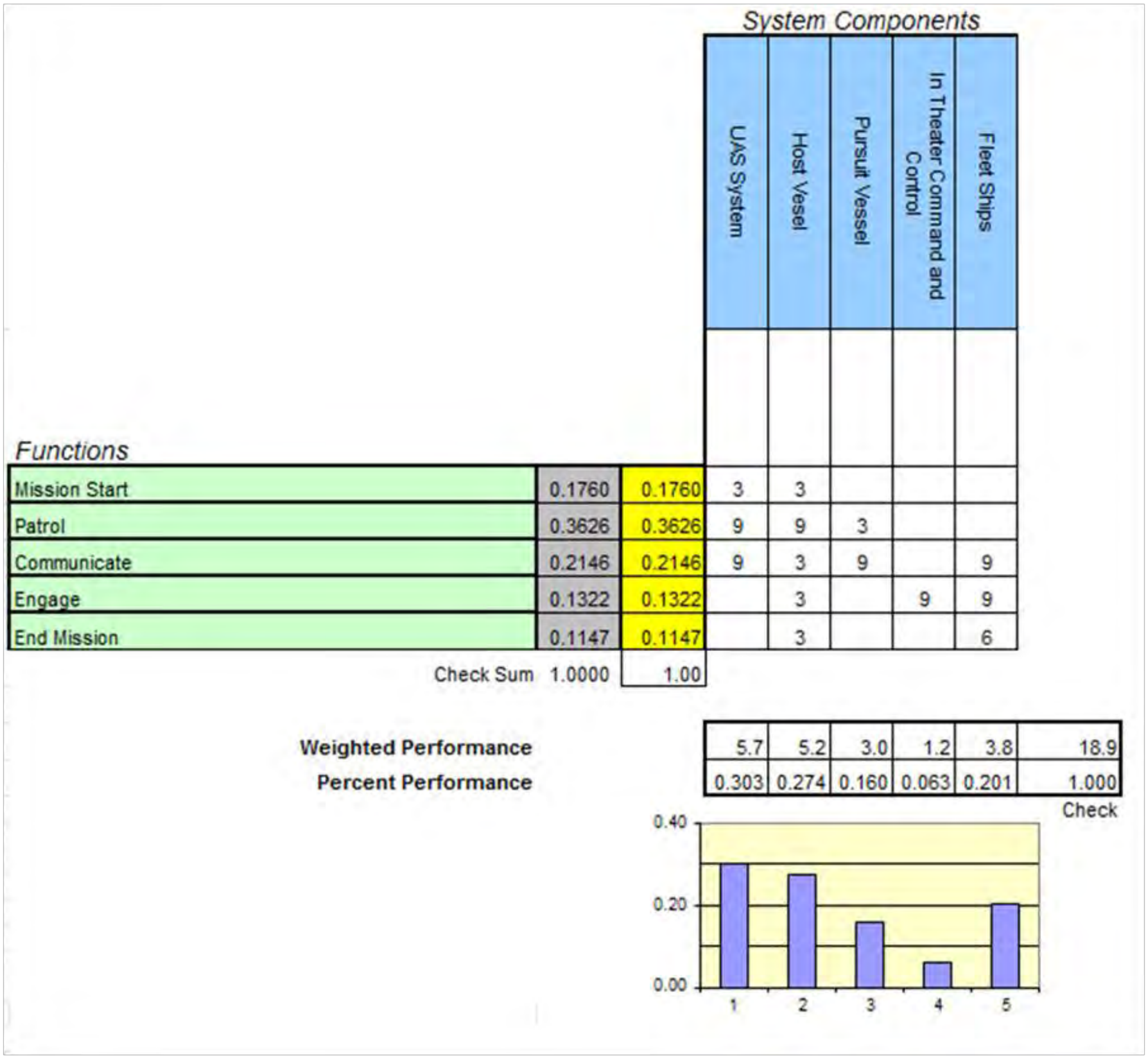


Figure 11. The “What‟s” versus the “How‟s” portion of the HOQ.

The Functions, which were introduced in the beginning of Chapter III, included Mission Start, Patrol, Communicate, Engage, and End Mission. The original stakeholder‟s weights and driving weights from the original AHP diagram drove OARS to be a primarily patrol based system. This was one of the leading requirements that caused OARS to rely heavily on Unmanned Aerial Support (UAS) systems and extended range mission profiles. Both Mission Start and Patrol, from the field of functions, received high marks on the matrix shown in Figure 11. This matrix starts to translate the OARS system‟s functions into the system physical architecture. These were the start of the design characteristics that were used to define the physical structure of the system.

The following HOQ matrix, Figure 12, is the matrix between Functions and Design Characteristics.



Functions			UAS System	Host Vesel	Pursuit Vessel	In Theater Command and Control	Fleet Ships	
Mission Start	0.1760	0.1760	3	3				
Patrol	0.3626	0.3626	9	9	3			
Communicate	0.2146	0.2146	9	3	9		9	
Engage	0.1322	0.1322		3		9	9	
End Mission	0.1147	0.1147		3			6	
Check Sum	1.0000	1.00						
Weighted Performance			5.7	5.2	3.0	1.2	3.8	18.9
Percent Performance			0.303	0.274	0.160	0.063	0.201	1.000
								Check

Figure 12. The Functions versus Design Components of the HOQ.

The Design Components were developed to reflect a flexible architecture needed to effectively meet the system functions. By meeting the system"s functions, OARS attempted to address the stakeholder"s needs and expectations. After completing an initial trade study on a top level element, the top level components were selected. The top level systems were based on feedback from stakeholders and industry representatives"

interviews and were chosen to allow flexibility for further analysis. The design components included a UAS system, a host vessel, a pursuit vessel, in theater command and control, and fleet ships. The UAS system consisted of all elements needed to support an unmanned aerial system. The UAS responsibility was to fulfill the primary functions of Detect and Communicate, and fulfill the driving objectives of Detect and Track pirate activities. The second most important element of the OARS system was the host vessel. The host vessel would act as the launch and recovery platform, detaining center, mobile base of operations for the UAS system, and pursuit vessel. The pursuit vessel was a system element designed to perform the Engage function and fulfill the objectives of Intercept and Neutralize pirate activities. The last two elements consisted of fleet ships and in-theater command and control. These two reflect the OARS system‟s primary role as a subset of a system of systems already in place. OARS was designed to seamlessly integrate with the multinational fleet in the area, to operate under possible command and control, and to work with American and allied shipping and fleet assets in the area.

Once the physical architecture was defined, the performances of the physical elements were compared to the desired target values using the MOEs. The MOEs were built in a manner so that they trace back to the objectives of the system. This ensures a mapping between the objective requirements and the measurable quantities. The MOEs were Detect, Classify, Track, Intercept, Neutralize and Communicate. These MOEs allowed for the direct measurement and comparison of the system and allowed for the rapid development of the performance parameters. The "Detect" MOE encompassed all aspects of detection and surveillance. The "Classify" MOE included all attributes from vessel databases to personnel decisions that were used to assess the hostility of a vessel. The "Track" MOE covered the system‟s capacity to monitor a vessel once it was determined to be suspect. The "Intercept" MOE, which had the lowest score of the MOE‟s, reflected the system‟s ability to match headings and velocities of the target vessels. The "Neutralize" MOE measured the OARS system‟s capability to reduce the known threats and make them inoperable or unable to carry out their intended role. Lastly, the "Communicate" MOE measured the systems capability to interface with both operational forces and with neutral shipping vessels. From these stakeholder weightings

and priorities, the KPPs could be selected from the list of derived performance parameters. These were then directly linked through the physical architecture through to the functions of the OARS system and were used to aid in the definition of the functional allocation. Table 4 shows the OARS KPPs.

Table 4. OARS System Key Performance Parameters (KPPs).

KPPs	Units of Measure	Threshold	Objective	Source
Percent of Detections	Probability	75%	100%	Derived from Anti-Piracy Study
Area Covered	Square nautical miles	390,000	1,100,000	Derived from Anti-Piracy Study
Sea State Operable	Beauford scale	2	5	Derived from Anti-Piracy Study
Targets Engaged	Number	1	10	Derived from Anti-Piracy Study
Number of Tracks	Number	1	10	Derived from Anti-Piracy Study
Time to Intercept	Minutes	24	16	Derived from Anti-Piracy Study
Number of Engagements	Number	1	10	Derived from Anti-Piracy Study
Number of Neutralizations	Number	1	10	Derived from Anti-Piracy Study
Safe Transit	% of ships to safely transit	98%	100%	Stakeholder Requirement
Number of Prisoners	Brig capacity	4	20	Stakeholder Requirement
Range of Communication	Miles	100	500	Derived from Anti-Piracy Study

The KPPs column shows a listing of the different KPPs. Following these are the units of measure. The KPPs are bound by the threshold and objective values. The threshold value was defined as the minimum required value for the OARS system to be operationally effective. The objective was the value that once exceeded, would not provide any further benefit to the system. The source column lists where the data was originally found. A detailed study of each attack in FY 10 through the first quarter of FY 11 revealed what values the OARS system needed to meet to respond to the pirate threats in and around the Gulf of Aden (ICC Pirate Attack Report 2010-2011). With the

threshold and objective values set, the following KPPs were determined to reflect the refinements of the need to deter piracy.

- The Percent of Detection attribute is the probability of sifting out a pirate threat from the background maritime traffic in the area. It reflected the success rate of finding a pirate threat in a given area.
- The Area Covered attribute was the square mileage of ocean that was needed to be covered to stop a pirate threat from operating in a given theater.
- The Sea State Operable attribute reflects the need for the OARS system to operate in the same conditions that the pirates are willing to tolerate.
- The Targets Engaged attribute reflect the number of skiffs and pirate vessels that could be independently engaged at one time during an operation.
- The Time to Intercept attribute was determined from the typical response time for current assets to respond to a vessel under threat.
- The Number of Engagements attribute reflects the number of independent operations the OARS system could conduct simultaneously.
- The Number of Neutralizations attribute reflects the number of targets engaged and neutralized, whether by lethal or non-lethal force.
- The Safe Transit attribute is the percentage of shipping vessels that the OARS system could guarantee safe passage through troubled seaways without incident.
- The Number of Prisoners attribute reflects the holding capacity of the OARS system while it is in operation. This is a critical aspect that is missing from the current CTF-151 system, since captured prisoners are forced to bunk in crew quarters until processed.
- The Range of Communication attribute determines the OARS system"s capability to communicate with its own deployed UAS systems and all neutral or friendly forces in the area.

With these quantities known, the system development process allowed for iteration and inputs into the modeling and simulation field. This allowed the OARS team to quickly and efficiently compare competing solutions to the OARS mission profile.

D. ARCHITECTURE

After the OARS system"s MOEs and KPPs were developed, the team then focused its attention on creating the architecture of the system. Developing the System Architecture is cornerstone in the system"s engineering process and aids in the fundamental development of the system. The overall System Architecture is decomposed into three core sections, which consist of Functional Architecture, Physical Architecture, and Allocated Architecture. The Functional Architecture defines what the system must do. The Physical Architecture represents the partitioning of physical resources available to perform the system"s functions (Buede 2009, pg 27). The Allocated Architecture is the mapping of the functions to resources or physical components. Allocated Architecture indicates the interfaces and data flow between systems or functions. This will be explained in Chapter III, Section 3, Allocated Architecture, through the use of an Integrated Definition for Function Modeling (IDEF0).

Each of the three architectural building blocks were detailed and outlined using CORE® 7, from Vitech Corporation. This tool provided a solution for managing and tracking requirements, building Functional-Physical Architectures, and simulating functional flow. It also allowed the team to create relationships and interfaces between elements to outline the Allocated Architecture, while allowing for configuration management of these architectural baselines. A summary of CORE® 7"s element relationship schema is shown in Figure 13. The elements of the diagram labeled as Item, Function, and Component, were the only elements configured into the baseline of the OARS system. However, all elements contributed to describing the overall System Architecture.

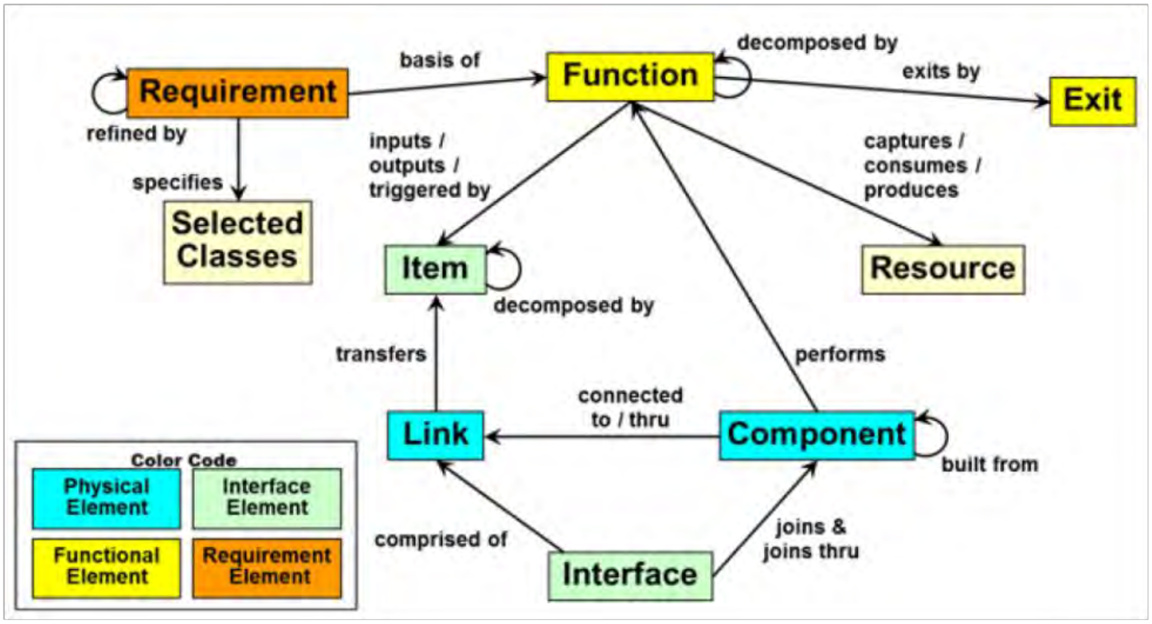


Figure 13. CORE® 7 System Engineering Element Diagram (from Vitech Tutorial 7. Pg 3)

1. FUNCTIONAL ARCHITECTURE

a. Functional Analysis

The Functional Analysis was developed to describe the functional requirements of the system and outline all that the system must do to complete its mission. This analysis also helped to identify basic internal and external functional interfaces, while aiding in the decomposition of upper-level functions. The analysis also aided in determining fundamental sequencing of these upper-level functions.

After analysis of current anti-piracy efforts (CTF-151) and collaboration with stakeholders, initial development of the Functional Hierarchy was completed. Figure 14 shows the top-level hierarchy of the key OARS functions that resulted from the Functional Analysis. These functions were grouped into distinct sequential operations, labeled as Detect, Fix/Classify, Track, Intercept, Neutralize Threat, and Communicate. In general, the OARS system will first detect a vessel. The OARS system will then work to identify the vessel and assess the risk of that vessel causing harm to another vessel. The OARS system will then begin to track that vessel. If triggered, OARS will then intercept a suspicious vessel and neutralize it. Throughout the process of these functions,

OARS will maintain multiple levels of communication internally and externally to its environment. A formal Functional Hierarchy was modeled in CORE where each function and sub-function is detailed in the subsequent section.

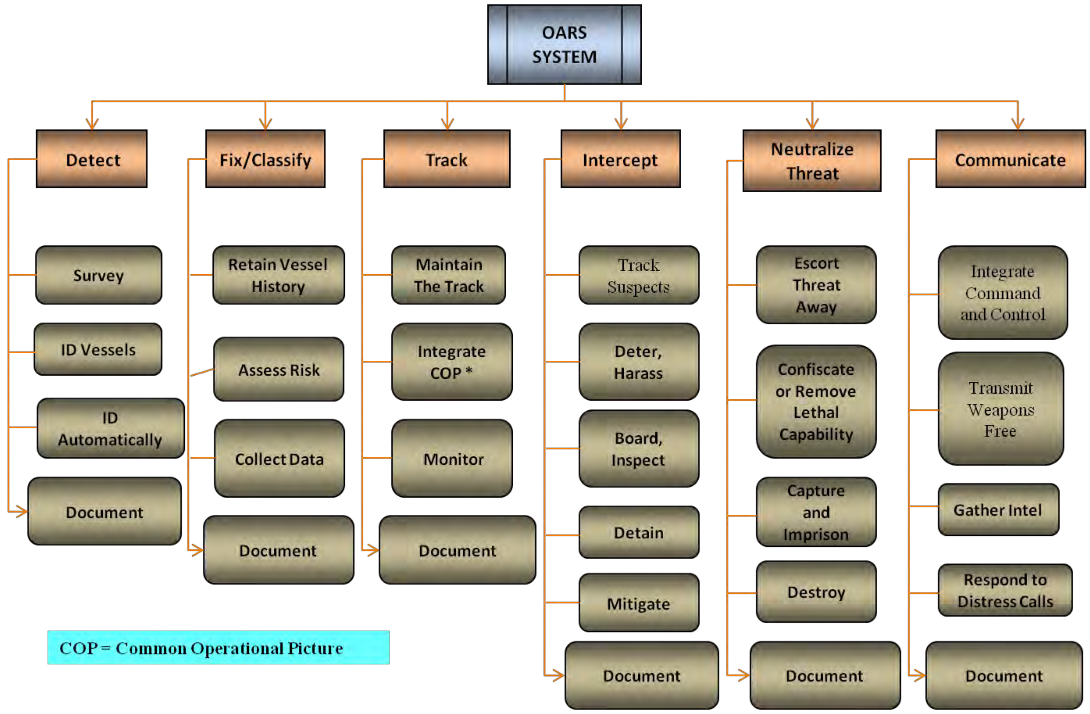


Figure 14. Stakeholder Functional Analysis

b. Functional Hierarchy

Using Figure 14, the Functional Analysis that evolved from the stakeholder‟s needs analysis, the team continued on in developing a formal Functional Hierarchy. This was developed using a combination of stakeholder input, team knowledge, current CTF-151 operational analysis, and the functional requirements of the system. The Functional Hierarchy was modified multiple times as the overall baseline was developed and functional deficiencies were revealed in the system architecture. Detect, Fix/Classify, Assess Risk, and Track, were combined in a functional area renamed as Patrol. Neutralize and Intercept were combined into the functional area of Engage. Mission Start and Mission End are functional areas that were added to indicate non-mission critical functions that are required for complete mission fulfillment.

Figure 15, Functional Hierarchy, is the formal organized tree developed from the Stakeholder Functional Analysis. Some functions were renamed, reclassified, or divided into sub-functions, which evolved throughout the architecture process. The five major functional areas (outlined in red) are decomposed into sub-functions (outlined in orange). Specific operational details of each sub-function are also indicated on the tree. Complete descriptions of the operational details are outlined in Chapter III, Section 3, Allocated Architecture.

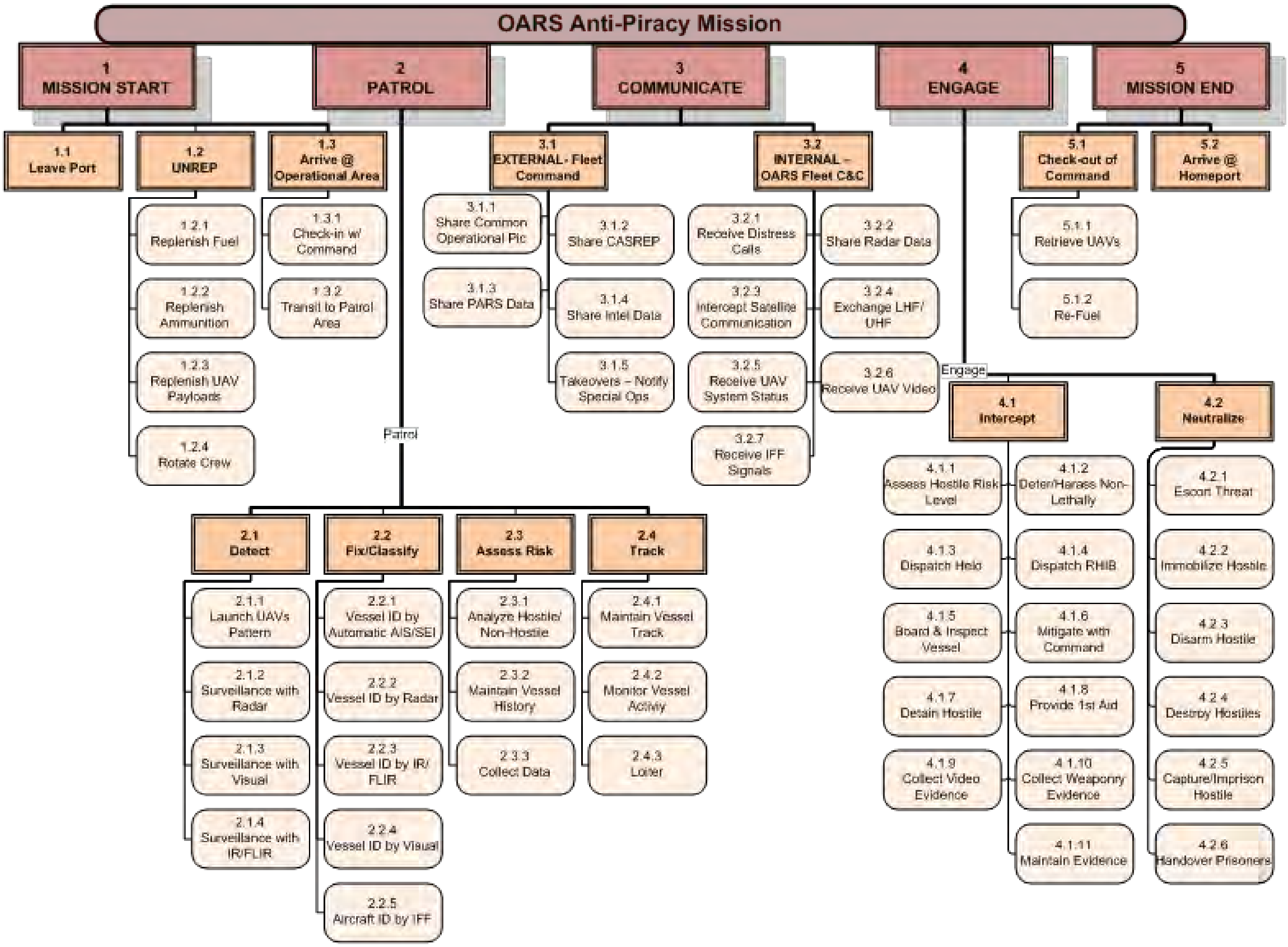


Figure 15. OARS Functional Hierarchy

2. Functional Flow Block Diagram (FFBD)

The Functional Flow Block Diagram (FFBD) is another way of organizing the elements of the Functional Architecture. After detailing most of the functions required by OARS, the flow and sequence of each was described since the Functional Hierarchy does not capture sequencing. Since the architecting process was iterative, some functions were added and others were reorganized. Outlining the functional flow helped to recognize gaps and deficiencies in the functional design. The FFBD also indicates recursive functions and functions that are conducted simultaneously. The flow of each function is described in detail from the Top Level (Level 1) down to the decomposed sub-function levels (Level 2 & 3).

a. Level 1 FFBD – OARS Mission Level

As outlined previously in the Functional Hierarchy, OARS has five main mission functions: Mission Start, Patrol, Engage Hostile, Communicate, and Mission End. After starting its mission, the OARS system begins patrolling an area and maintaining vital communication with external and internal systems. If hostile activity is found, the OARS system will be invoked to engage that hostility. This process repeats itself until mission orders are given to end the mission. The mission level functionality is then completed. Each of these five functions will be explained in detail. However, the third-level FFBD breakdowns are included in Appendix B.

The flow of each function is shown in Figure 16. It must be noted that the annotations at the bottom of each box are actual top-level components that are mapped to the corresponding function. This is part of the Allocated Architecture, which is further explained in Chapter III, Section 3, Allocated Architecture.

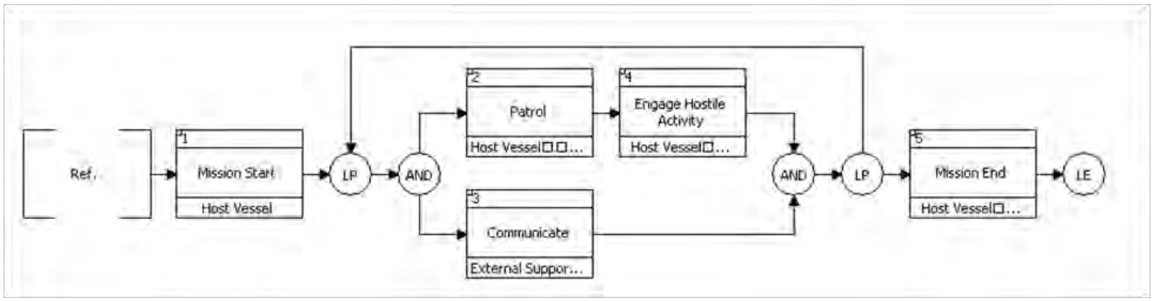


Figure 16. Top Level FFBD for the OARS System.

b. Level 2 FFBD – 1 Mission Start

Figure 17 illustrates that the first step of Mission Start is to leave home port. It will transit to its intended destination as outlined in its orders. If needed, the OARS system conducts an Underway Replenishment (UNREP) to refill fuel, supplies, and ammunition. It then arrives at the intended operational area and checks in with the area commander.

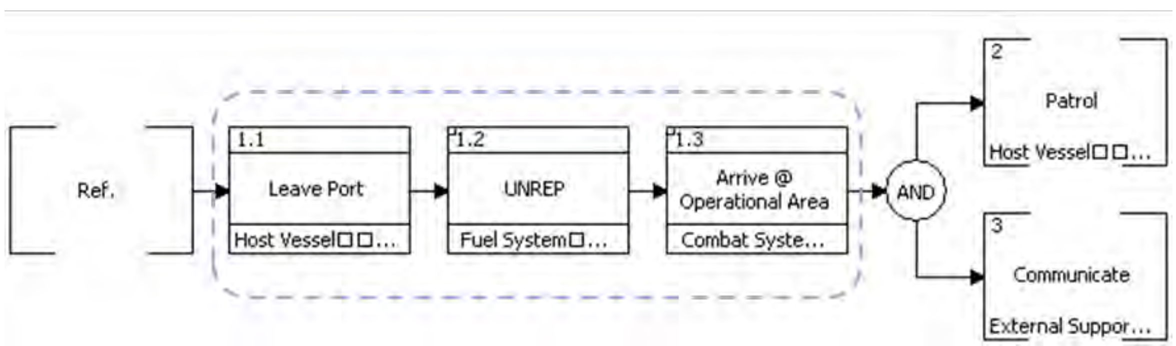


Figure 17. FFBD 1.0, „Mission Start."

c. Level 2 FFBD – 2 Patrol

After completing the Mission Start, OARS patrols its assigned area and conducts surveillance. This can be seen in Figure 18 within the area that is encompassed by the blue-dotted line. Patrolling includes everything except formal engagement. OARS must first detect a vessel before it can classify it and conduct a risk assessment. If the risk assessment is high, then OARS will maintain track of that vessel or vessels. It

continues to detect and classify vessels as incoming observations continue. The Patrol function cycles throughout the mission until it is invoked to end the mission.

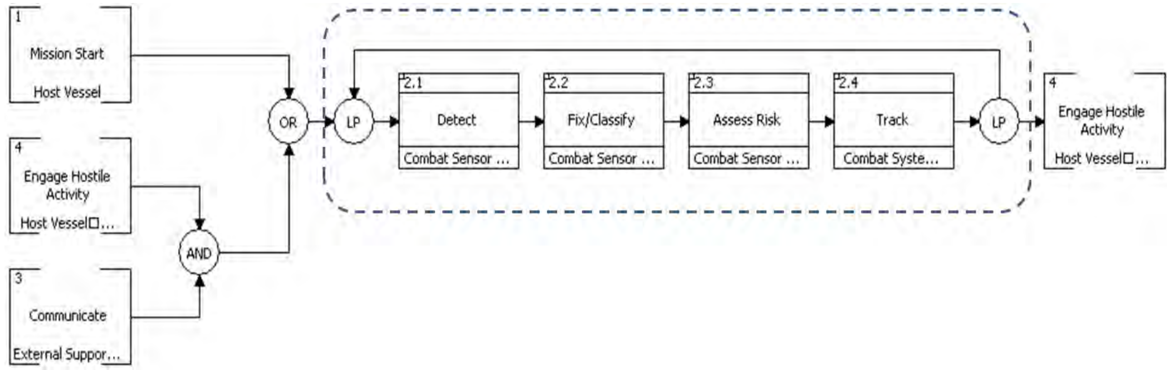


Figure 18. FFBD 2.0, „Patrol."

d. Level 2 FFBD – 3 Communicate

Figure 19 shows the simultaneous communication functions performed by OARS. Communicating externally includes sharing the following with ally units: a Common Operating Picture (COP), Pirate Attack Risk Surface (PARS) data, and other intelligence. Communicating externally also includes notifying the fleet of hostile situations.

Communicating internally includes receiving UAV reconnaissance data, intercepting pirate communication channels, and exchanging information between the individual systems that comprise the overarching OARS system. Note how the Communication function is repeated throughout the cycle. It is conducted throughout both Patrol and Engagement functions.

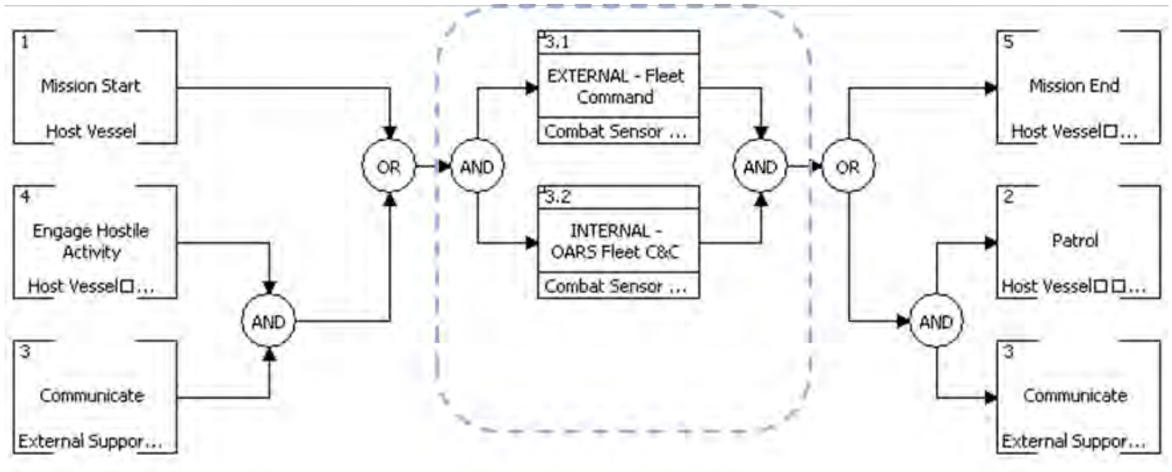


Figure 19. FFBD 3.0, „Communicate."

e. Level 2 FFBD – 4 Engage Hostile Activity

While conducting a patrol, OARS may be invoked to intercept and neutralize a hostile vessel as indicated in the functional flow of Figure 20. This function involves assessing the risk of the situation, deploying the pursuit vessel, and deterring and/or boarding the hostile vessel to ascertain acts of piracy. At this time, arrests may be made and evidence may be collected. This function is also referred to as a VBSS (Visit, Board, Search, and Seizure). If the hostile vessel is seen as having a high level of risk, it is immobilized or destroyed to nullify an escalating situation. Prisoners and evidence are handed over to local authorities. It was emphasized by stakeholders that the OARS system must obtain video evidence, as this is the strongest anti-piracy weapon in theater. After completion of engagement, OARS continues its mission of Patrol and Engagement.

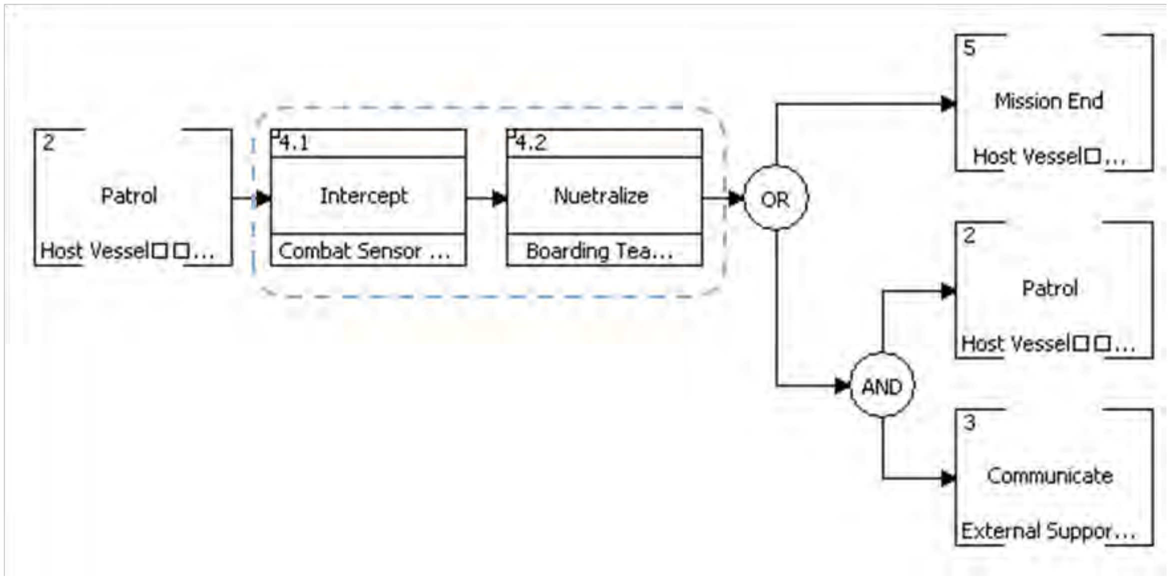


Figure 20. FFBD 4.0, „Engage Hostile Activity.‟

f. Level 2 FFBD – 5 Mission End

When invoked by Mission Orders to end the mission, OARS discontinues its Patrol and Engagement functions. OARS first retrieves its UAVs, checks out with its commander, and then returns to its homeport. This is shown in Figure 21.

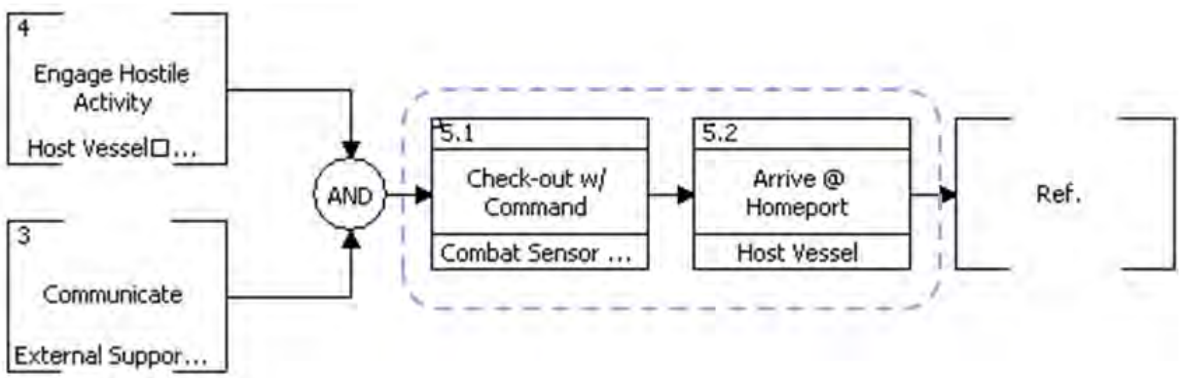


Figure 21. FFBD 5.0, „Mission End.‟

2. PHYSICAL ARCHITECTURE

The generic Physical Architecture detailed the components and resources assigned to build a physically operating system. Stakeholder feedback and the OARS team‟s informal feasibility analysis were both incorporated into the design of the Physical Architecture. The Physical Architecture was developed in parallel with the Functional

Architecture. As the system functions were elaborated, the physical systems needed to satisfy these functions were specified. Technology Readiness Levels (TRL) were also considered in the generation process. The Physical Architecture has many uses, including aiding in the design of the Work Breakdown Structure (WBS) and aiding in the generation of alternatives which is further explained in Chapter III, Section E, Alternative Generation.

The majority of the components and systems used by OARS have already been successfully fielded in today‟s Navy. These components include Littoral Combat Ships (LCS), RHIBs, and navigation systems. Some components may either currently already be developing systems with high TRLs or would require further development in order to obtain higher TRLs. Developmental systems like these would include UAV launch & recovery systems for multiple UAVs, or additional storage systems for contraband/evidence or detainees. The system is designed to easily incorporate the use of additional reconnaissance systems such as Broad Area Maritime Surveillance System (BAMS) or augmented reconnaissance airships, which are not listed as a part of this architecture.

Referring to Figure 22, the system is broken into two sections: Internal OARS Systems (A.1) and External Support Systems (A.2). The External Support System is a grouping of physical systems external to the OARS system that help to satisfy some of the functions needed for a successful OARS mission. As stated in the background of the problem, the Anti-Piracy effort in the Gulf of Aden includes foreign navies, thus OARS must include them as a part of its operation. These external support systems are primarily involved during engagement with hostile vessels.

Internal Systems are decomposed into the Host Vessel, Pursuit Vessel, and Unmanned Aircraft Systems (UAS). The lighter-blue boxes are the sub-systems of each individual system, which may be further decomposed into components. The UAS System includes the UAV and its launch & recovery system. The Pursuit Vessel consists of a RHIB boat or SH-60 Sea Hawk Helicopter, depending on the situation, capabilities of the Host Vessel, and the mission requirements. The Host Vessel contains the majority of the OARS components. In addition to the standard operating equipment contained on

a LCS or DDG ship, the Host Vessel also contains multiple UAS control stations and additional storage areas for evidence, contraband, and detainees until they are relinquished to authorities.

The next section, Allocated Architecture, is where the Functional and Physical Architectures come together. The functions in Figure 15 are satisfied by the sub-systems in Figure 22. The interactions and details of each sub-system are fully discussed in that section.

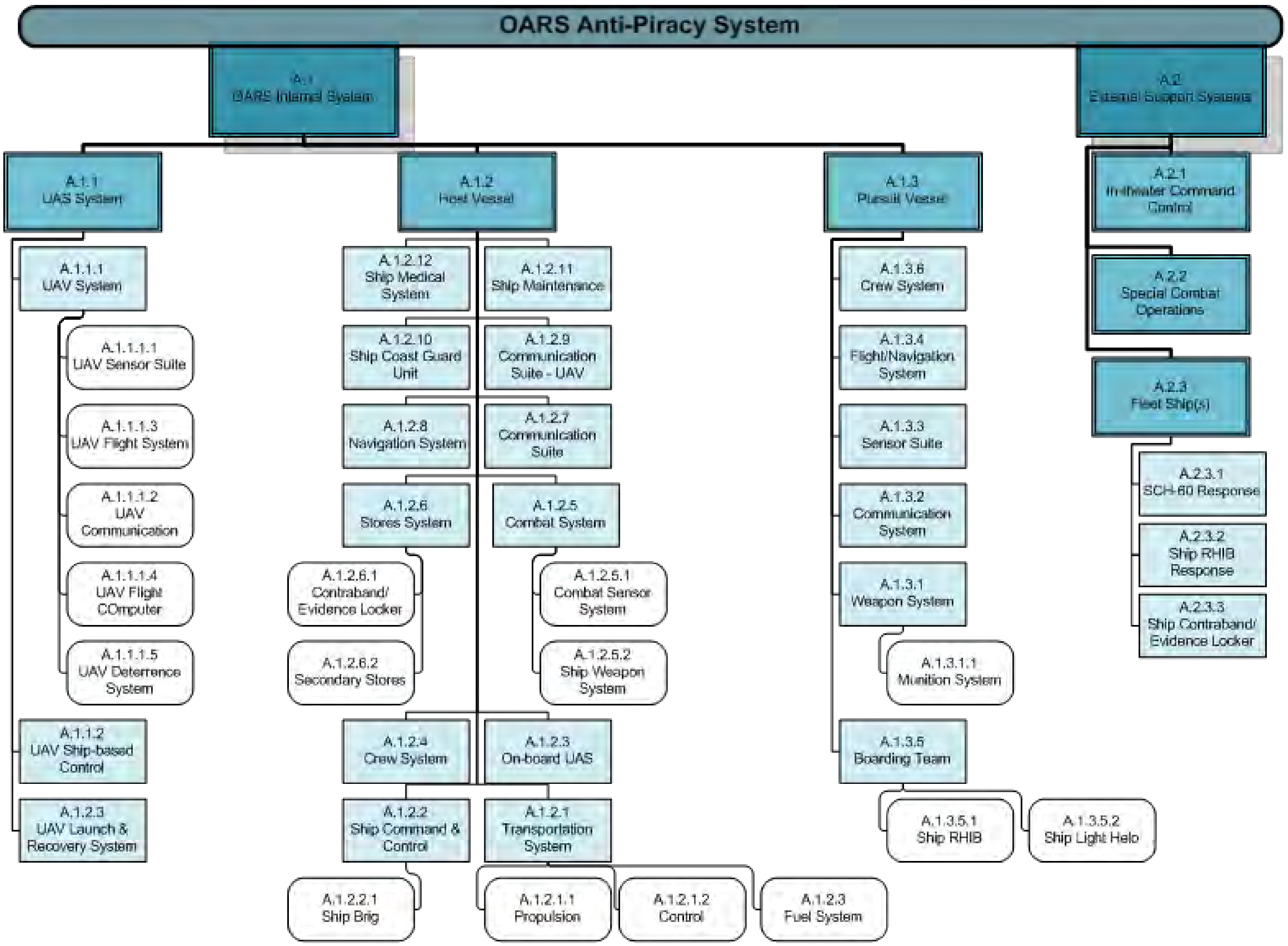


Figure 22. OARS Physical Hierarchy.

3. ALLOCATED ARCHITECTURE

Development of the Allocated Architecture is a system engineering activity in which the entire process comes together (Buede 2009, pg 84). It integrates the requirements with the Functional and Physical Architectures. According to Buede, the Allocated Architecture is associated with five major development activities which include:

- Trace system-wide requirements to system and derive component-wide requirements.
- Define and analyze functional activation and control structure.
- Conduct performance and risk analysis.
- Document architectures and obtain approval.
- Document subsystem specifications.

Reflecting on the OARS methodology, some of these developmental activities were done independently of the Allocated Architecture process. Performance and Risk Analysis were conducted early in the design process during the generation of the CONOPS. Information from this analysis was then directly incorporated into the generation of the Physical Architecture.

System and component-wide requirements were developed in Chapter III, Section A, System Requirements. Stated as a functional requirement in Section A, "The OARS System must Detect, Track, Engage, Neutralize Targets, Provide Safe Transit, and Comply with international maritime law." A physical requirement mandates the use of UAVs that are capable of conducting surveillance by capturing live-video. These requirements are traced to corresponding functions, indicating their satisfaction by the way of functions and physical components. This is a part of the Allocated Architecture, but is not explicitly detailed in this section.

As mentioned earlier, the Functional and Physical Architectures were managed using the software program, CORE® 7. These architecture baselines were installed into the program to allow proper organization and traceability documentation. The Functional and Physical Architectures were mapped together to produce the Allocated Architecture.

Stakeholders were presented fundamental descriptions of the architectures and concurred with its design.

The team created IDEF0 diagrams using CORE® 7. IDEF0 diagrams indicate interfaces, data flow, information, physical items, system control, and functional control, all while highlighting the physical systems that satisfy each functional activity. IDEF0 depictions highlighted any misallocations and deficiencies in the operation. They may also be reviewed for necessary input and output operations. The involved functions were organized into a step-like fashion down and to the right with ample control triggers, feedback loops, and input/output arrows. Functions, which are labeled in red, are referred to as "Elements." Physical systems, which are labeled in blue, are referred to as „Components." Physical items, data, and information are referred to as „Items." Items are the black arrows which represent the flow of data, information, or physical items. They may be either inputs or outputs to a function, and they may also be responsible for the control of each function or sub-function. In the following section, each top-level function of the Functional Hierarchy is outlined in detail, including its sub-functions.

a. Level 1 IDEF0 – OARS Mission Level

Figure 23 shows that a typical OARS mission starts with the Mission Start function, which is first invoked by Mission Orders. Although Mission Orders is a trigger and manipulates the functionality of certain functions, it also contains data which is fed as inputs to the Mission Start and Patrol functions. Once Mission Start is enabled, OARS will depart port, complete an UNREP, and transit to its operating area before checking into Fleet Command. This function is satisfied by the Host Vessel.

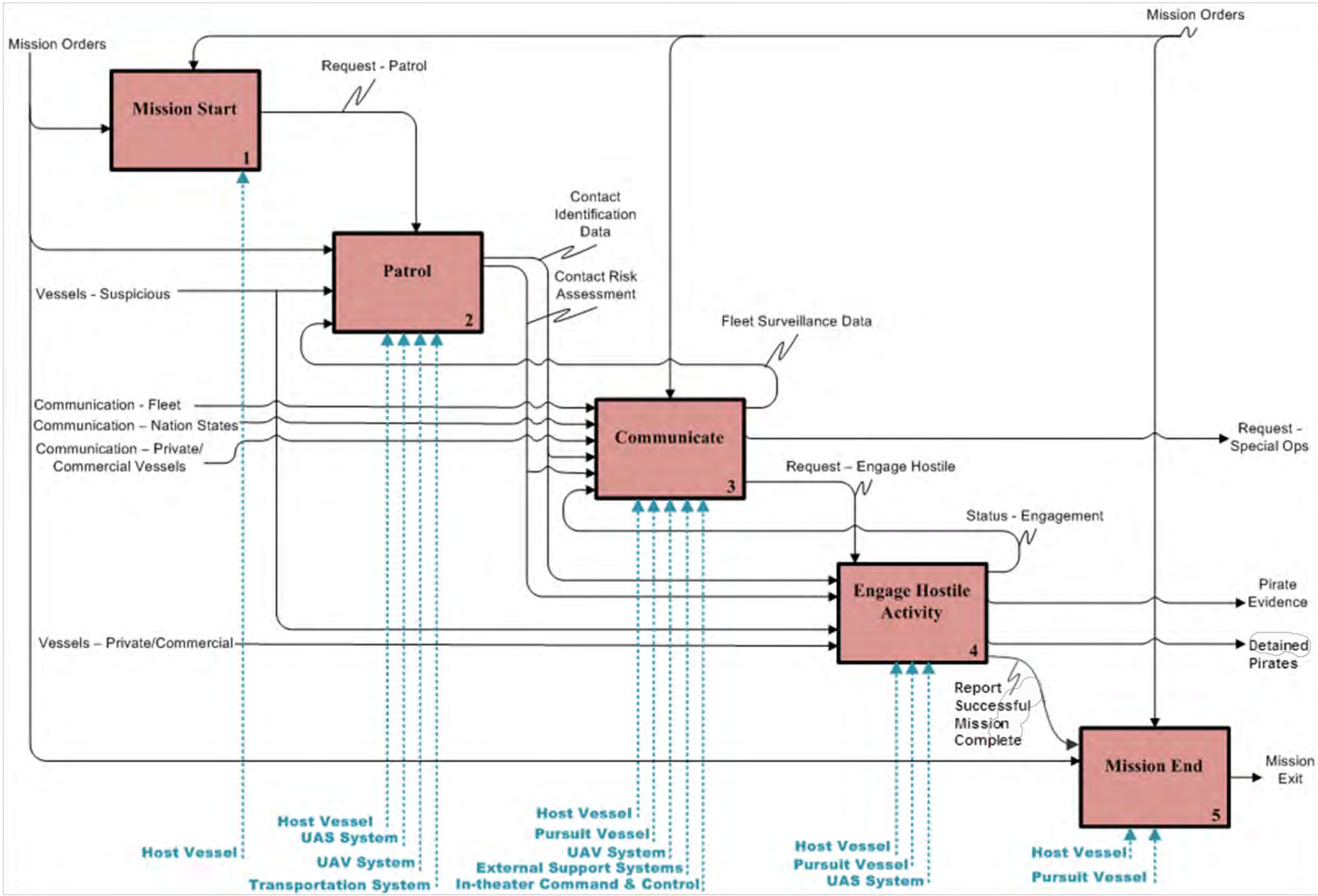


Figure 23. OARS IDEF0 – Mission Level.

After check-in, a Patrol Request is made to start surveillance routines. This includes detecting vessels, classifying them, assessing their risk, and tracking them. In particular, surveillance is directed towards Suspicious Vessels that have either been identified by civilian vessels, or that have been identified by the OARS UAVs as having pirate paraphernalia (i.e. ladders, drums of fuel, etc.). Physical Systems involved with Patrol are the Host Vessel, UAS Host Platform, UAV System and the Host Vessel"s Transportation/Propulsion System. Patrolling areas are determined based on Mission Orders and external Fleet Surveillance Data.

Fleet Surveillance Data that is fed into Patrol, originates from external communication with the fleet and other vessels. The Communicate function encompasses all internal and external communication for the OARS system. Externally, OARS communicates with the Fleet, Commercial/Private Vessels, and other Nation States or allies that are collaboratively operating in the area. Internally, Communicate includes communication with both the OARS"s UAVs and Pursuit Vessels, as well as the sharing of surveillance data. Additionally, it receives information from the Patrol and Engage functions. It communicates its Engagement Status with suspicious vessels and receives Contact Risk Assessment data from its Patrolling function. Physical Systems involved with Communicating are the Host Vessel, Pursuit Vessel, UAV System, Command & Control, and External Support Systems such as CTF-151 or allies. Communicate functions are controlled by the Mission Orders, which dictates how it communicates and with whom.

OARS may receive information about hostile situations from its patrol or communication with the fleet and civilian vessels. If the hostile situation involves the hijacking of a civilian vessel, then OARS sends outs a Request Special Operations command for an external Special Forces team to intervene. If OARS is instructed to intervene upon a particular hostile situation, an Engage Hostile Request is initiated. This triggers the function, Engage Hostile Activity. Contact Identification Data and Risk Assessment Data are fed into this function from Patrol. Civilian Vessels and Suspicious Vessels interact with this engagement. OARS will first attempt to intercept the vessel and stabilize the situation. If not, then it proceeds to neutralize the hostile vessel. A

VBSS is conducted, which may result in arrests of Pirates and collection of Pirate Evidence related to the incident. Pirates and associated evidence are transferred to appropriate authorities for prosecution. The Host Vessel, Pursuit Vessel and UAS System are the physical OARS systems involved in this function. The Engagement Status is continually communicated internally and to other external fleet vessels. As discussed earlier regarding functional flow, OARS will return to Patrolling or end its mission after completion of Engaging Hostile Activity.

When a typical OARS mission ends, the determination is controlled by the Mission Orders. Mission End includes retrieving UAVS, checking-out with the fleet command, completing an Underway Replenishment (UNREP), and transiting back to the homeport. These functions are satisfied by the Host Vessel and Pursuit Vessel, which conclude a complete OARS Mission.

b. Level 2 IDEF0 – 1 Mission Start

The start of a typical OARS mission does not vary extensively from a typical USN DDG or LCS"s mission start, as the initial platform for OARS is derived from these vessels. To begin a mission, Mission Start functions are first initiated by a request to leave port, generated by Mission Orders. After the vessel leaves port, UNREP functions are initiated. Crew members are assigned to their tasks, and UAS supplies, fuel, and ammunition are loaded to the OARS system or depleted supplies are replenished. After UNREP is reported complete, the OARS system will continue onto its operational area. After arriving at its operational area, the Host Vessel checks-in with Fleet Command, receives its current orders, and then initiates its patrol. Figure 24 outlines the physical systems involved and the control of each function.

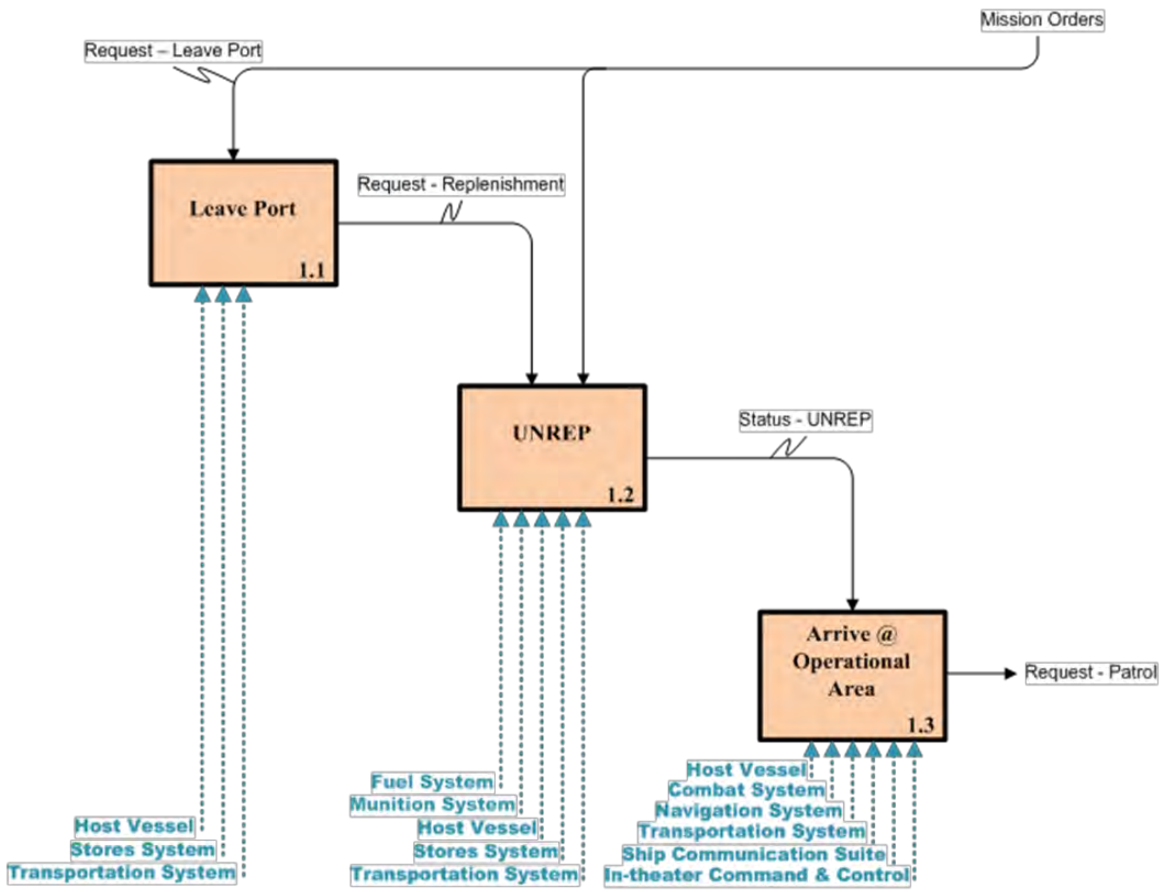


Figure 24. IDEF0 1.0, „Mission Start."

c. Level 2 IDEF0 – 2 Patrol

The Patrol function is the largest set of operations conducted by OARS. In involves Detecting, Classifying, Assessing Risk, and Tracking. Each of these sub-functions involves detailed operations and interfaces with other OARS functions.

As mentioned previously in the Mission Level diagram of Figure 23, the Patrol function receives Mission Orders and external Fleet Surveillance Data while interacting with pirates. The Patrol function is performed by the Host Vessel and UAS System. To other functions, the Patrol function must output Contact Identification Data which is coupled with a Contact Risk Assessment of anything it identifies within its Patrol.

The Patrol function first starts with Detect. Request Surveillance starts the process while Fleet Surveillance is fed into it to help determine surveillance plans. A pattern of UAVs are launched into the assigned operational area, and surveillance is conducted through radar, IR/FLIR, and the interpretation of video or visual data. The UAV Sensors, Ship-Based Control unit, and ship‟s Combat Sensor System participate in this function. Raw OARS surveillance data is fed into the Tracking and Fix/Classify functions. Contact Identification Data is a specific vessel profile which contains identification data, risk assessment, surveillance data, tracking data, and vessel history.

Fix/Classify strictly involves identifying vessels and tagging them each with a unique identifier for tracking purposes. Differentiating suspected pirates from local civilians has posed the largest problem for the anti-piracy efforts. Classifying each vessel properly is a critical requirement of this function: hence there are many systems involved in determining classification. Information retrieved from the UAV is combined with information from the ship and fleet to identify vessels. These inputs are surveillance data and tracking information. Once a contact is classified, the Risk Assessment function is triggered to determine the risk of a specific contact.

The Assess Risk function receives external Fleet Surveillance Data, Contact Identification Data from the Fix/Classify function and also Tracking Data from the Track function. Similar to the Fix/Classify function, many of the same systems are involved in assessing a contact‟s risk. A contact is determined to be hostile or non-hostile based on information received from classification, the vessel‟s known track, and retained history of the vessel. After analysis, the Contact Risk Assessment is mutually shared with other OARS systems and to the Fleet.

The Track function also receives the Contact Risk Assessment information. After being invoked by a detection from the Detect function, it builds a database based on the Contact Risk Assessment. Paired with Contact Identification Data, OARS will use this information throughout its overarching Patrol function to aid in classification and risk assessments of all contacts. Tracking of suspicious vessels and all contacts will be fulfilled through use of the UAVs, ship combat systems, and the contact database stored within. Additionally, information in the database is intermittently

communicated to the fleet through use of the OARS Communicate function. The IDEF0 representation of these interfaces, data, and functions, are shown in Figure 25.

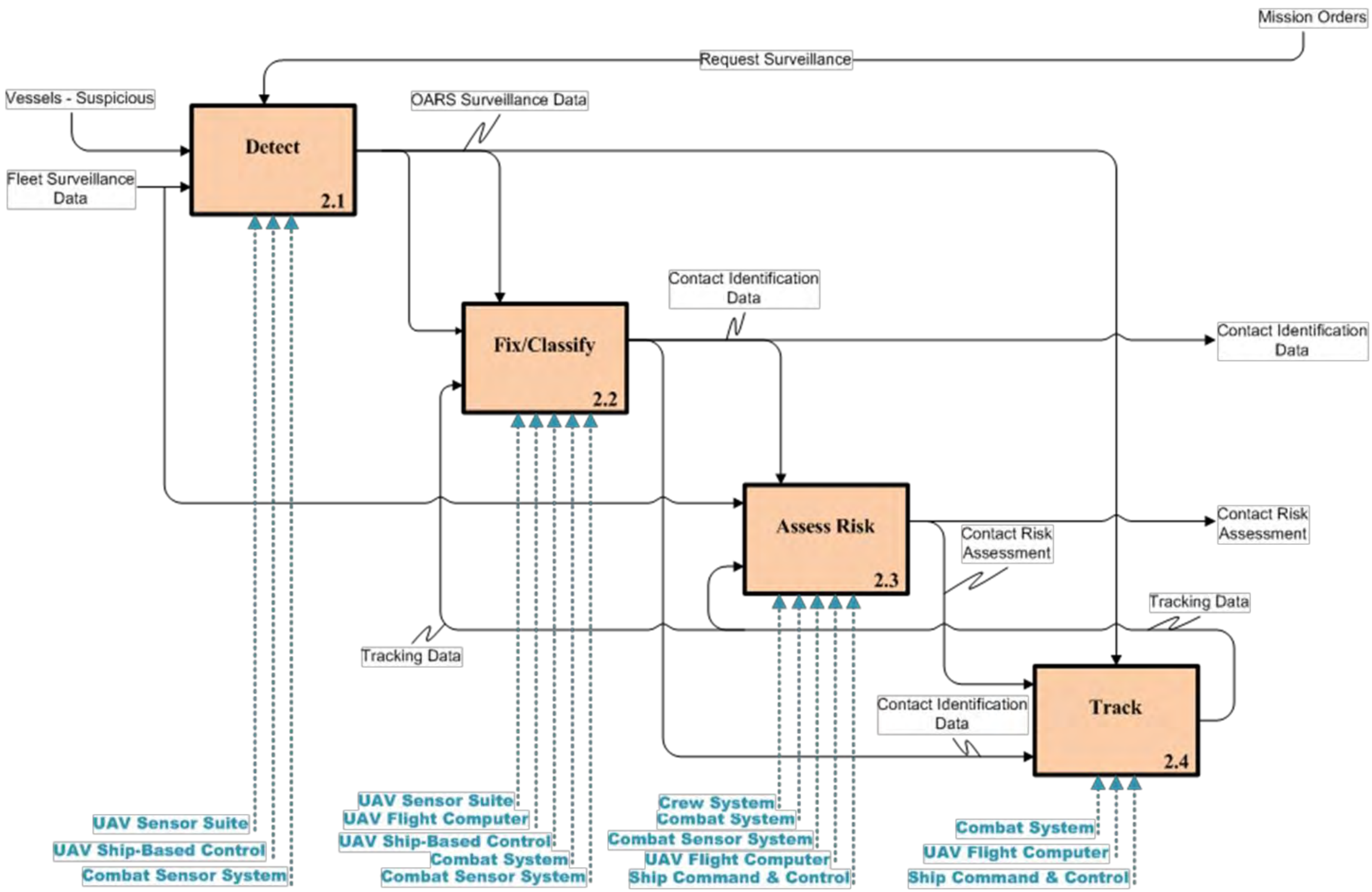


Figure 25. IDEF0 2.0, „Patrol."

d. Level 2 IDEF0 – 3 Communicate

To ensure fluid and efficient operations, OARS must be capable of communicating externally to fleet operations and internally to its other systems. As mentioned previously, the Patrol function shares Contact Risk Assessment information and Contact Identification data with the Communicate function. While this function is invoked from the start of the mission, how it communicates and with whom it communicates are determined by the Mission Orders.

OARS communicates externally with the Fleet, Nation States, and Civilian Vessels. It receives Fleet Surveillance Data from the Fleet and shares Contact Risk Assessment and Identification Data with them as contributions to the Common Operating Picture (COP). If it is in engagement with another vessel, it will share that status information as well. In general, OARS will share information such as CASREP reports, PARS prediction data, intelligence information, COP, and also request the assistance of an external Special Operations team if a civilian vessel has been hijacked. OARS does not directly engage with vessels that have already been hijacked since its primary mission is surveillance and deterrence. The OARS host vessel can host Special Operations forces if necessary.

Internally, OARS Command & Control communicates with its UAVS, Pursuit Vessel, and its helicopter-based Pursuit Craft. It receives surveillance data through data links, which are communicated between various Patrol and Intercept functions. It also intercepts UHF, LHF and satellite information that typical pirates use in their piracy missions. Some of the capabilities involved with the internal communication function are sharing radar data, communicating with the UAVs, exchanging LHF/UHF, intercepting pirate communications and receiving distress calls.

The Ship Communication Suite is the center of all communications, whether internal or external. It serves as a link between communicating externally and communicating internally. Almost every system in OARS has some level of communication, which may not be directly linked to the Ship Communication Suite. For example, the On-board UAS Control Station communicates directly with all UAVs. Information received from the UAVs is then shared with the Ship Communication suite

by way of the onboard UAS. Figure 26 indicates all the physical systems which participate in each communication domain.

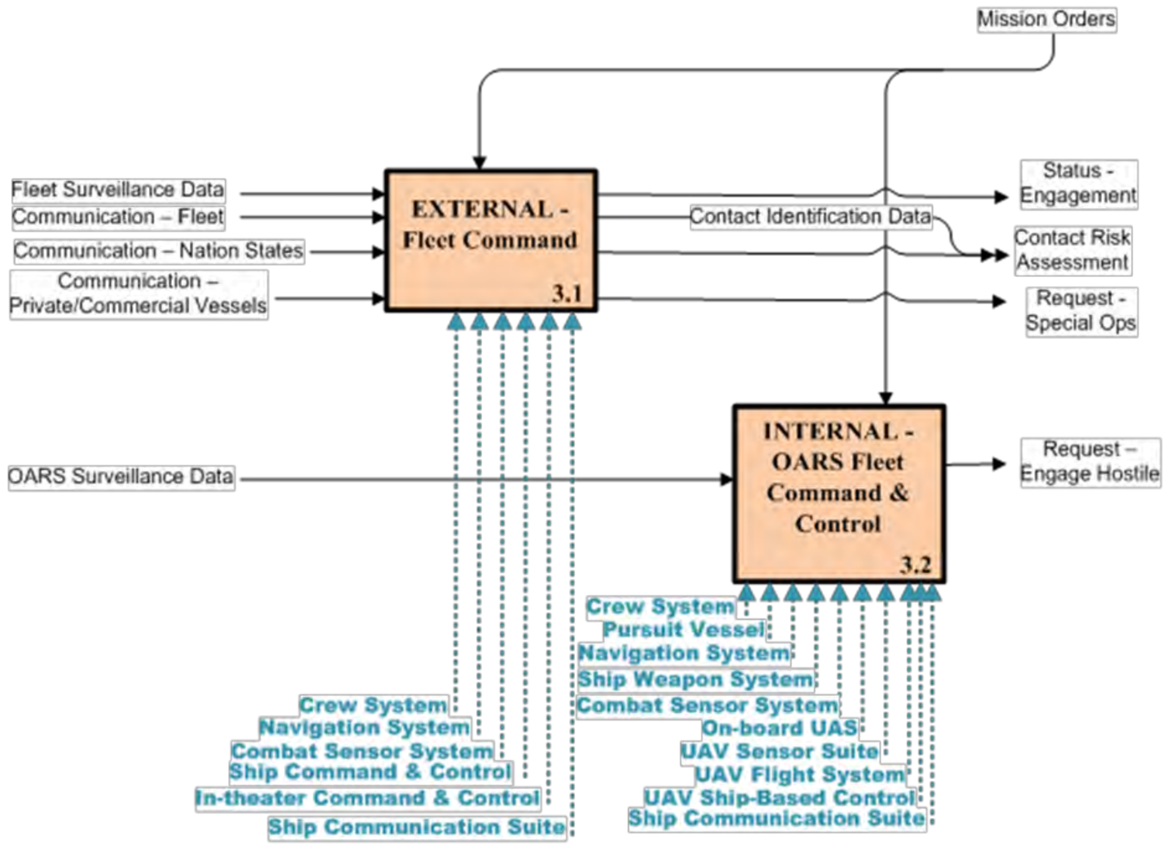


Figure 26. IDEF0 3.0, „Communicate."

e. Level 2 IDEF0 – 4 Engage Hostile Activity

On a typical mission, OARS continually patrols while communicating information it receives. If it interprets a situation to be hostile or encounters a suspected pirate, it will attempt to engage that hostile. Engage Hostile Activity is invoked by a request from the Communicate function which originally stems from Fleet Surveillance Data, Communication with Civilian Vessels, or Contact Risk Assessment Data obtained through surveillance. Engaging Hostile Activity is served primarily by the Pursuit Vessel, but supplemented with the UAV and Host Vessel.

The request to engage a hostile is first received by the Intercept function. This complex function receives any information from the Contact Risk Assessment,

Civilian Vessels, and the Suspicious Vessels themselves. When the request for engagement is made, the Intercept function first selects the method of interception. This is decided between the OARS Command & Control and the Fleet Command and Control. Requests are then made to dispatch the Pursuit Vessel, a helicopter or a RHIB, along with a selected Boarding Team. If the UAV is equipped with a non-lethal deterrence system, such as a smoke screen or noise maker, it may participate in the deterrence function. After dispatching is complete, the Pursuit Vessel crew may or may not board the contact vessel. If so, a VBSS continues which may result in the collection of evidence and the arresting of pirates. Video evidence collected by the Pursuit Vessel and UAVs is also collected as evidence and is transferred to the Contraband/Evidence Locker and the database of vessel history. After deterrence is complete, pirates are given first aid, if required. The Pursuit Vessel also continually relays its engagement status internally to the OARS Command & Control, which also includes the risk level of the hostile contact. When the risk level of the hostile activity reaches a certain height, the Pursuit Vessel may relay a request to OARS Command & Control to neutralize the hostile activity. This is the control trigger for another function, Neutralize, as shown in Figure 27.

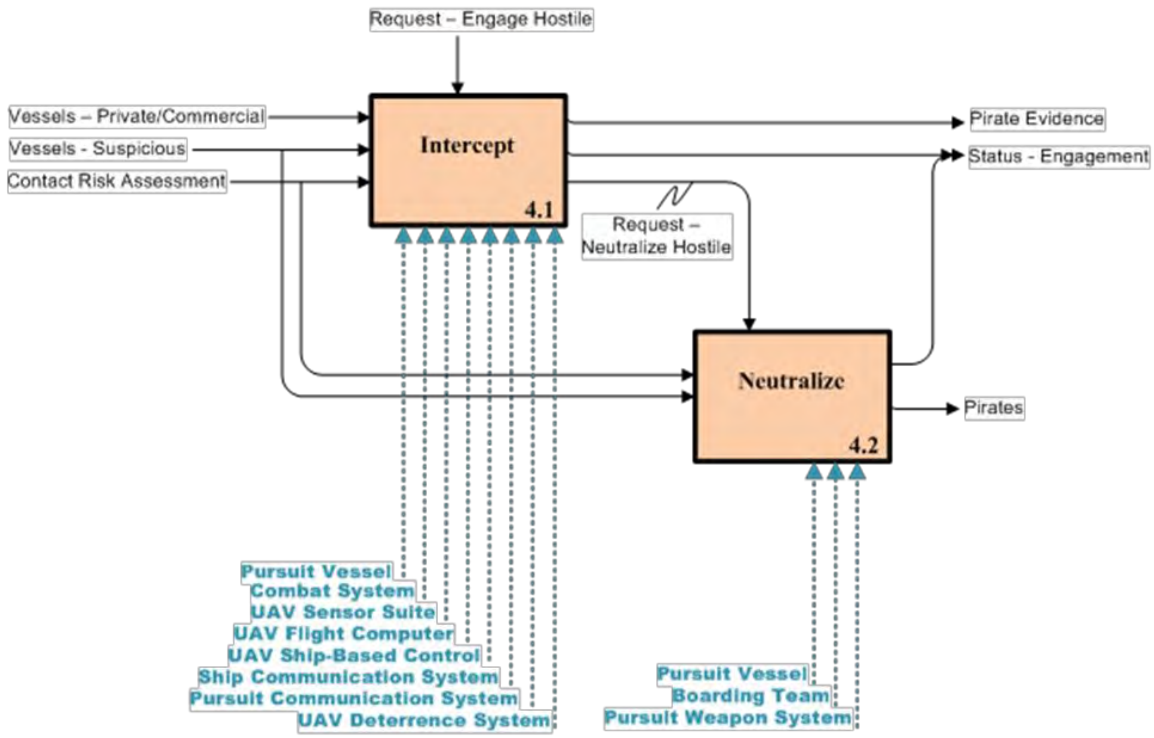


Figure 27. IDEF0 4.0, „Engage Hostile Activity."

Neutralize is invoked by the Intercept function, when the hostile activity reaches an intolerable level of risk. It is satisfied by the Boarding Team and Weapon System operating on the Pursuit Vessel. Weapon support from the Host Vessel is provided, if needed. The goal of the Neutralize function is to disarm, immobilize, and capture the hostiles in a joint effort to minimize the potential loss of life. This includes deterrence of a potential hijacking. OARS holds this function as the last resort of elevated pursuit, before notifying special operational forces of OARS"s failure to deter.

The request to neutralize hostile gives the Pursuit Vessel permission to forcefully escort the threat away from the civilian vessel. The boarding team is consistently fed updated information about the pirate vessel and other local threats throughout the Neutralize process. If escorting the threat fails, the team attempts to immobilize the hostile personnel. After immobilization, the pursuit team is invoked to disarm, capture and imprison hostiles. However, if the Pursuit team fails to immobilize,

the contacts" risk assessment is asserted as imminent danger. The Boarding Team then proceeds to destroy the hostile contact. Remaining prisoners and evidence are collected and the engagement status is relayed to OARS Command & Control. The prisoners are given first aid before they and their associated contraband are handed over to prosecuting authorities. A resulting failure of the Neutralize function indicates that the civilian vessel has been hijacked and hostile activity now becomes a situation for the special operational forces, a scene external to the allocated architecture of OARS.

f. Level 2 IDEF0 – 5 Mission End

The conclusion of the OARS mission is dictated by the Mission Orders. Unless the OARS system becomes substantially operationally deficient, it carries out its functions throughout the duration of the mission. The Mission End process first checks out with Command. The UAS System requests retrieval of all UAVs currently in flight. The Host Vessel refuels through completion of an Underway Replenishment (UNREP). After arriving at its homeport, OARS exits the mission, indicating mission completion.

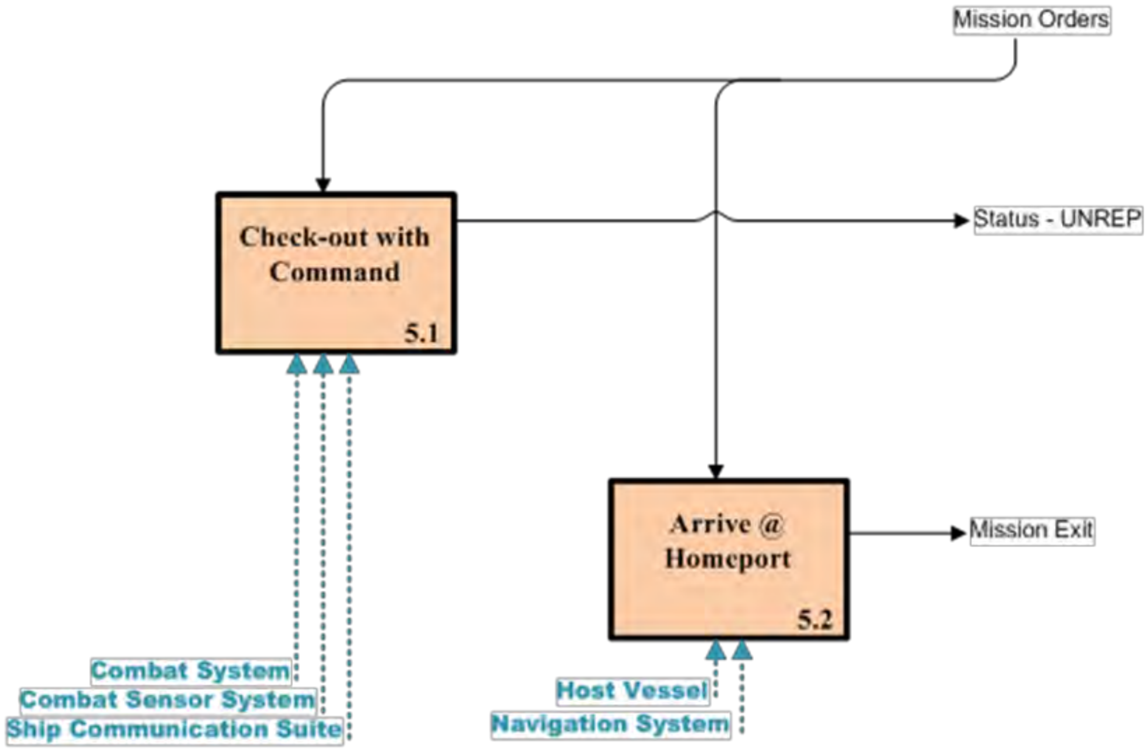


Figure 28. IDEF0 5.0, „Mission End."

E. ALTERNATIVE GENERATION

The alternatives generation phase began early during the research phase of our capstone project. Our team sought to answer the question: "How will we meet the needs of the customer?" During that phase, the design team used brainstorming techniques so as to not limit itself to an early solution. This section will review some of the proposed solutions and then use relevant information gathered to identify which of our alternatives were not viable and why. The alternatives that the team found to be viable are summarized in this section.

The project team was tasked to design a system that will utilize existing surface warfare assets alongside UAV assets to counter an expanding threat to surface merchant trade ships and private vessels by pirate gangs. The alternatives generation portion of the project included exploring the ability to utilize the current government off-the-shelf (GOTS) systems. GOTS takes existing surveillance and detecting systems and integrates

them into a new OARS System. The team evaluated alternatives from a variety of articles and developers on the need for a pirate interdiction system to be used around the globe for preventing crimes on the high seas toward commercial vessels. Systems deployed on U.S. Navy ships in the Gulf of Aden, aircraft used during visit, board, search, and seizure (VBSS) activities within CTF-151, and airborne UAVs used to monitor activities in the Middle East region, all provided mature technology to be uniquely assembled for this new system design.

The system was bounded primarily by the capabilities, configuration, and interfaces of the host ship. The most well suited surface ship available is the new Littoral Combat Ship (LCS); the surface warfare module was well matched for surface search and target prosecution.

1. Materiel Alternatives Developed

The OARS team attempted to configure different alternative solutions from different configurations of systems. This allowed the OARS team to then settle upon the best alternatives before moving onto the modeling and simulation effort. Our physical alternatives were developed based on our top-level systems which we considered variable and highly valuable to overall system effectiveness. These physical systems, chosen from Figure 22, were the UAS System, Host Vessel platform, Pursuit Vessel platform, Weaponry, Combat Systems, and Surface Sensors. Remaining physical systems did not have significant variable impacts to overall OARS effectiveness, thus were not considered when the team determined alternatives.

a. Alternative #1.1

The first design alternative, “Single Platform with Stand Alone Operations” is intended to perform detection, tracking, and prosecution functions. It is called the “single system cell” since it does not rely on any other systems external to the OARS to perform the capability. The detection capabilities that are performed include nine ScanEagle UAVs, and the prosecution capability is supported with the use of two USMI pursuit vessels with double barreled .50 caliber machine guns mounted forward of

the conning structure. Due to the fact that a modified version of Spain‟s DORNA (Dirección de tiro Optrónica y Radárica NAval) fire control system has been integrated into the U.S. Navy‟s first two LCSs, the DORNA fire control system was implemented into Alternative #1.1‟s configuration. The complete list of systems included with this alternative is shown in Table 5.

Table 5. Single Platform (Stand Alone Operations) List of Systems.

Combat Systems	Hard Kill The weapons	Surface Sensors
Net Central C4ISR	Host Ship; MK 110- 57 mm Gun (1)	EADS TRS-3D C-band **radar** (air / surface surveillance LCS-1
Secure Communication Crypto	50 Cal Machine Guns (4)	Sea Giraffe AMB 3-D Radar
Common Operational Picture	AGM-114; Hellfire missile (4)	EO/IR Camera (Star SAFIRE)
Fire Control; DORNA	M60; 7.62 mm Machine Gun	DORNA EO/IR Camera
Sensor Processing		ScanEagle UAV
SH-60 Helicopter		

b. Alternative #1.2

The second design alternative is the "Single Platform Stand Alone Version with an alternative UAV sensor named ExDrone." This alternative is intended to use the OARS for detection, tracking and prosecution functions; however, it will use an alternative UAV. The combat systems category remains the same as with the first alternative. In the surface sensors category, our team has attempted to match the capability of the on-board UAV SAR radar and EO/IR camera. The complete list of systems included with this alternative is shown is Table 6. Even though this alternative

utilizes a different UAV, the total number of persons required to operate it remains the same (two per shift).

Table 6. Single Platform (Stand Alone Operations) List of Systems.

Combat Systems	Hard Kill The weapons	Surface Sensors
Net Central C4ISR	Host Ship; MK 110- 57 mm Gun (1)	EADS TRS-3D C-band **radar** (air / surface surveillance LCS-1
Secure Communication Crypto	50 Cal Machine Guns (4)	Sea Giraffe AMB 3-D Radar
Common Operational Picture	AGM-114; Hellfire missile laser guided (4)	EO/IR Camera (Star SAFIRE)
Fire Control; DORNA	M60; 7.62 mm Machine Gun	DORNA EO/IR Camera
Sensor Processing		ExDrone UAV
SH-60 Helicopter		

c. Alternative #1.3

The third design alternative is the Single Platform with a change to the surface and airborne pursuit vessels. The surface vessel is being changed to a Zodiac rigid hulled inflatable boat, and the airborne pursuit vessel is being changed to a MQ-RB Fire Scout unmanned helicopter.

The Fire Scout has started to make a name for itself in recent Naval missions. Just recently, during the 2011 Lybian Civil War, a MQ-RB Fire Scout was used in targeting missions under NATO command. The Fire Scout is denoted as a Vertical Takeoff Unmanned Aerial Vehicle (VTUAV).

The cost of operating a VTUAV in place of a manned SH-60 helicopter is significantly less. The U.S. Navy expects to acquire delivery of three new Fire Scouts this year and twelve more aircraft in 2012. According to one report, Congress has been

asked to boost the funding for this VTUAV by $46 Million in 2012 to raise the inventory to a total of 56 aircraft by the end of 2012 (Ackerman 2011). The difference in this alternative would be most notably the use of a weapons platform UAV. The manning requirements of this solution are very low, at three officers and three enlisted technicians per UAV system compared with 19 total staff to support an air detachment for an SH-60 Sea Hawk (Raymer 2009, 31) (Stracker 2007, pg. v). The complete list of systems included with this alternative is shown is Table 7. Even though this is an unmanned UAV pursuit aircraft, it was determined that there would be a requirement for two UAV operators aboard the host ship.

Table 7. Single Platform (Stand Alone Operations) List of Systems.

Combat Systems	Hard Kill The weapons	Surface Sensors
Net Central C4ISR	Host Ship; MK 110- 57 mm Gun (1)	EADS TRS-3D C-band **radar** (air / surface surveillance LCS-1
Secure Communication Crypto	50 Cal Machine Guns (4)	Sea Giraffe AMB 3-D Radar
Common Operational Picture	AGM-114; Hellfire missile laser guided (4)	EO/IR Camera (Star SAFIRE)
Fire Control; DORNA	Two pods of four 70mm folding wing Hydra rockets	DORNA EO/IR Camera
Sensor Processing	Advanced Precision Kill weapons laser guided	ExDrone UAV
Fire Scout VTUAV	Viper Strike precision munitions	

d. Alternative #1.4

The fourth design alternative is hosted by the Littoral Combat Ship (LCS). With this alternative, the team would not alter the OARS significantly outside the UAV sensor. This alternative is shown in Table 8.

Table 8. Single Platform (Stand Alone Operations) List of Systems.

Combat Systems	Hard Kill The weapons	Surface Sensors
Net Central C4ISR	Host Ship; MK 110- 57 mm Gun (1)	EADS TRS-3D C-band **radar** (air / surface surveillance LCS-1
Secure Communication Crypto	50 Cal Machine Guns (4)	Sea Giraffe AMB 3-D Radar
Common Operational Picture	AGM-114; Hellfire missile laser guided (4)	EO/IR Camera (Star SAFIRE)
Fire Control; DORNA	Two pods of four 70mm folding wing Hydra rockets	DORNA EO/IR Camera
Sensor Processing	Advanced Precision Kill weapons laser guided	ExDrone UAV
Fire Scout VTUAV	Viper Strike precision munitions	

e. Alternative #1.5

The fifth design alternative found additional options in the host ship. The exceptional Command, Control, and Communications capability with the LPD would be available as a single cell vessel in company with additional destroyers and frigates combined specifically in a set of six to cover the Gulf of Aden transit corridors. The extensive aircraft facilities onboard the LPD offers the six system cells ample support but which also require maintenance and repair facilities afloat. With this alternative, the team would build a duplicate system around the host ship as in alternative 1.1. This Alternative is shown in Table 9.

Table 9. Single Platform (Stand Alone Operations) List of Systems.

Combat Systems	Hard Kill The weapons	Surface Sensors
Net Central C4ISR	Host Ship; MK 46 Mod 1- 30 mm Gun (2)	Thermal imager director Camera

Secure Communication Crypto	MK26 Mod 18 50 Cal Machine Guns (2)	Northrop Grumman Norden Systems AN/SPS-73 surface search radar operating at I-band (2)
Common Operational Picture	AGM-114; Hellfire missile laser guided (4)	Lockheed Martin AN/APQ-9B surface surveillance and tracking radar operating at I band
Sensor Processing	M60; 7.62 mm Machine Gun	ScanEagle UAV
SH-60 Helicopter		
MK 2 SSDS will be an integration of all the ship's self-defense systems and will include multi-function radar, advanced integrated electronic warfare system and infrared search and track system (IRST).		

f. Alternative #1.6

The sixth design alternative is the LPD host ship upgrade with the Fire Scout VTUAV. With this alternative, the team would build a system around an alternative RHIB named Zodiac. The advantages to the Zodiac RHIB over the USMI is in a larger personnel capacity and its increased speed, which is slightly more at 48 knots (versus 46 knots). Additionally, the cost is a quarter of that of the USMI vessel. This alternative is shown in Table 10.

Table 10. Single Platform (Stand Alone Operations) List of Systems.

Combat Systems	Hard Kill The weapons	Surface Sensors
Net Central C4ISR	Host Ship; MK 46 Mod 1- 30 mm Gun (2)	Thermal imager director Camera
Secure Communication Crypto	MK26 Mod 18 50 Cal Machine Guns (2)	Northrop Grumman Norden Systems AN/SPS-73 surface search radar operating at

		I-band (2)
Common Operational Picture	AGM-114; Hellfire missile laser guided (4)	Lockheed Martin AN/APQ-9B surface surveillance and tracking radar operating at I band
Sensor Processing	M60; 7.62 mm Machine Gun	ScanEagle UAV
Fire Scout VTUAV	Two pods of four 70mm folding wing Hydra rockets	
MK 2 SSDS will be an integration of all the ship's self-defense systems and will include multi-function radar, advanced integrated electronic warfare system and infrared search and track system (IRST).	Advanced Precision Kill weapons laser guided	
	Viper Strike precision munitions	

g. Alternative #1.7

The seventh design alternative is the fifth alternative with the alternative UAV sensor, ExDrone. With this alternative, the team would be able to measure the effectiveness of the alternate UAV with the more advanced LPD support package, considering that the deployment of large numbers of UAVs and Fire Scout armed VTUAVs has not occurred to date. The maintenance requirements necessary to sustain this configuration will be valuable modeling and simulation data. This alternative is shown in Table 6.

Table 11. Single Platform (Stand Alone Operations) List of Systems.

Combat Systems	Hard Kill The weapons	Surface Sensors
Net Central C4ISR	Host Ship; MK 46 Mod 1- 30 mm Gun (2)	Thermal imager director Camera

Secure Communication Crypto	MK26 Mod 18 50 Cal Machine Guns (2)	Northrop Grumman Norden Systems AN/SPS-73 surface search radar operating at I-band (2)
Common Operational Picture	AGM-114; Hellfire missile laser guided (4)	Lockheed Martin AN/APQ-9B surface surveillance and tracking radar operating at I band
Sensor Processing	M60; 7.62 mm Machine Gun	ExDrone UAV
SH-60 Helicopter		
MK 2 SSDS will be an integration of all the ship's self-defense systems and will include multi-function radar, advanced integrated electronic warfare system and infrared search and track system (IRST).		

2. OARS's Zwicky's Morphology

The seven alternatives were evaluated using a combination of procurement costs and mission requirements. A procurement cost analysis was conducted to determine the host vessel with the least cost to be utilized by the OARS system. Since the CONOPS described the use of six individual OARS systems working together to provide coverage throughout the entire Gulf of Aden, a total of six different host vessels was required. This cost analysis can be found in Appendix E. A combination of six Littoral Combat Ships (LCS) was the cheapest of the host ship combinations. The LPD and DDG platforms are considerably more costly to build than the newer LCS ships, at over a billion dollars each. Another issue arises with the fact that FFG class ships will not be procured in the future. The OARS team also noted that integrating several UAVs with two ground control stations across three different ship classes would be difficult. Due to these issues, alternatives 1.5, 1.6 and 1.7 were eliminated immediately.

The OARS team then evaluated how each of the other alternatives measured up to the mission requirements. This process was facilitated using a simple Zwicky‟s morphological box, which is located below in Table 12. Mission requirements were placed into five categories:

1. Combat systems
2. Sensors
3. Capture and Detention
4. Weapons
5. UAV Endurance

Table 12. Zwicky‟s Morphological Box.

Combat Systems	Sensors	Capture and Detention	Weapons	UAV Endurance
LCS ★ ▲ ✦ ●	IR ★ ▲ ✦ ●	Armed, Manned Helo ★ ▲	LCS ★ ▲ ✦ ●	< 5 hrs ▲ ●
COP ★ ▲ ✦ ●	EO ★ ▲ ✦ ●	Armed, Manned Pursuit Boats ★ ▲ ✦ ●	Helo ★ ▲ ✦ ●	5-15 hrs
SA ★ ▲ ✦ ●	Video ★ ▲ ✦ ●	Brig Facility ★ ▲ ✦ ●	Pursuit Boats ★ ▲ ✦ ●	> 15 hrs ★ ✦
Net Centric ★ ▲ ✦ ●				
GCS ★ ▲ ✦ ●				
High Altitude UAV ★ ▲ ✦ ●				

★ = Alternative 1.1
▲ = Alternative 1.2
✦ = Alternative 1.3
● = Alternative 1.4

The remaining alternatives adequately supported combat systems, sensors, and weapons requirements. Alternatives 1.1 and 1.2 satisfy the "capture and detention" requirement the best by including a SH-60 helicopter. Alternatives 1.3 and 1.4 utilize the MQ-B8 Fire Scout VTUAV instead of the SH-60 helicopter. The VTUAV is a very capable system and has a lower life cycle cost than the SH-60, however, due to its limited "capture and detention" capabilities, it was not considered as a preferred option for the OARS system. The SH-60 will also prove more valuable in keeping detected pirates at bay until the pursuit vessels arrive. For this reason, Alternatives 1.3 and 1.4 were not considered as optimal for the OARS system.

The next subsystem evaluation criteria examined by the OARS team was the endurance of the UAVs. Although the ExDrone UAV option was found to be less costly, it suffers when it comes to endurance. Its mission is limited to less than 5 hours, while the ScanEagle has an endurance of over 18 hours. Much more time will be spent searching for pirates over a much greater area if the ScanEagle UAV is used instead of the ExDrone. Both Alternatives 1.1 and 1.3 utilize the ScanEagle UAV and therefore they both perform the best when it comes to UAV endurance. Due to the fact that Alternative 1.1 provides both a strong "capture and detention" capability and provides a very large UAV endurance range, it was selected as the most preferred alternative. Alternative 1.1 can be adjusted to add up to 12 ScanEagles per OARS system. The simulation will also evaluate an augmented configuration incorporating a long range airship such as BAMS.

3. Recommended Alternatives

a. Alternative 1, Basic OARS

Due to the results of the Zwicky"s Morphology Box, Alternative 1.1 will be carried into the analysis phase of the systems engineering process and will be considered as "Basic OARS." The subsystems that will make up Alternative 1 are detailed in Table 5.

b. Alternative 2, Augmented OARS

The other alternative that was selected to be modeled had the same configuration as Alternative 1.1, but also was augmented by Wide Area Surveillance airships or BAMS. This allowed the OARS team to analyze the benefits of adding a land-launched airship to the Basic OARS system to allow for greater surveillance of pirate activity. The analysis of both alternatives is further discussed in the next Chapter.

IV. MODELING AND ANALYSIS

A. TOOLS AND APPROACH

The Naval Simulation System (NSS) software package, which was used for modeling and simulation (M&S) of the OARS system, was developed by the Space and Naval Warfare Center SPAWAR (PD-15) (Information Support Systems) and Metron Inc. from Reston, VA. This software uses object-oriented Monte Carlo Modeling to simulate complicated interactions between individual objects. NSS is centered around the support of operational commanders in developing and analyzing operational events that are driven by either decisions made, or the selected courses of action at a mission group or force level.

The OARS Team used the scenario based modeling within NSS for the purpose of establishing base-line functional models, applying variances to the models to test each alternative effectively, and capturing the necessary data from alternatives in order to compare quantitative output values. This provided the team with a set of feasible alternative system arrangements that were tested against the identical constraints. This helped to frame the best solution to this system.

The basis of selecting NSS was primarily because of its capability for modeling two opposing forces in a dynamic environment with a geographic world overlay for reference. Each study was primarily focused on reducing the number of successful pirate attacks based on known effective deterrents. Specific resources can then be allocated to experimental combinations of surface ships, helicopters, and UAVs, with the overall goal of deterring piracy. Allocating specific resources primarily refers to having compatible combinations of surface combatants loaded with accompanying helicopter crews and a UAV detachment, working together to combat the threat of piracy. The allocation of experimental resources refers to combining relatively untested combinations of resources. Examples of these untested resources were a blimp-like airship and an array of UAVs that were deployed to assist in combating the threat of piracy. The individual scenarios setups in NSSs will be laid out in more detail in the "Model Scenario" section of this chapter.

The basic methodology when conducting OARS system modeling and simulation (M&S) was to provide a multi-preference objective model that allowed the Measures of Effectiveness (MOEs) to be weighed in accordance with the systems engineering process. The MOEs were measures drawn from the original stakeholder requirements and mapped to the available outputs from the NSS program scenarios. Table 13 below lists the MOEs that were used to establish the modeling criteria. The MOEs were taken from default MOE templates available within the NSS program.

Table 13. Measures of Effectiveness (MOEs).

Name	Rank	Template (NSS)
Red Assets Destroyed (Pirates Overtaken)	1	Asset Destroyed
Blue Assets Destroyed (Cargo Ships Overtaken)	2	Asset Destroyed
Red Weapon Launches (Pirate Overtake Attempts)	3	Weapon Launched
Blue Weapon Launches (OARS Overtake Attempts)	4	Weapon Launched
Blue Surveillance Classifications (OARS)	5	Surveillance Classifications
UAV Cumulative Launches (OARS)	6	Aircraft Cumulative Launches
Blue Surveillance Detections (OARS)	7	Surveillance Detections

Throughout the following explanations of the modeling setup, red and blue assets will refer to the two opposing forces that were set up in NSS to model the behavior of the OARS system and its components. NSS and the two opposing forces are discussed in further detail below. The MOEs were an integral portion of the model design and were necessary in comparing the various system alternatives. The MOEs were gathered as outputs from the model. Results from the model are outlined in further detail in the "Results" section of this chapter.

Modeling efforts were focused on accurately simulating pirate and cargo ship activity in the Gulf of Aden to cover approximately 390,000 square miles of effective

piracy interdiction. The simulation efforts continually grew from the modeling successes where initial run data was able to pass basic validity tests of plausible and non-plausible data. The initial analysis of such data helped to produce a confidence in the data that was being produced while modeling the current CTF-151 system and the alternative OARS scenarios. These efforts were accomplished by using NSS‟ study management and export tools to output multiple replications of scenarios to Microsoft Excel for analysis. The more robust tools within the NSS proved to be more difficult to master as students, but perseverance and assistance from the OARS‟s capstone advisor allowed the group to successfully model four separate alternative scenarios.

While modeling OARS, two opposing forces (red and blue) were created. The blue forces consisted of U.S. Navy surface ships, UAVs, and merchant vessels. These blue forces were pitted against the red forces, which consisted of red pirate surface craft who were attempting to hijack and ransom merchant vessels. Scenarios were developed by introducing specific ship paths, tactics, defensive actions, and hostile actions. Background information, such as the origin of pirate attacks and known merchant shipping lanes, were learned during the OARS team‟s initial piracy research. Figure 29 below shows a NSS screenshot displaying the cargo tracks used as a baseline to simulate the busiest corridor through the Gulf of Aden.

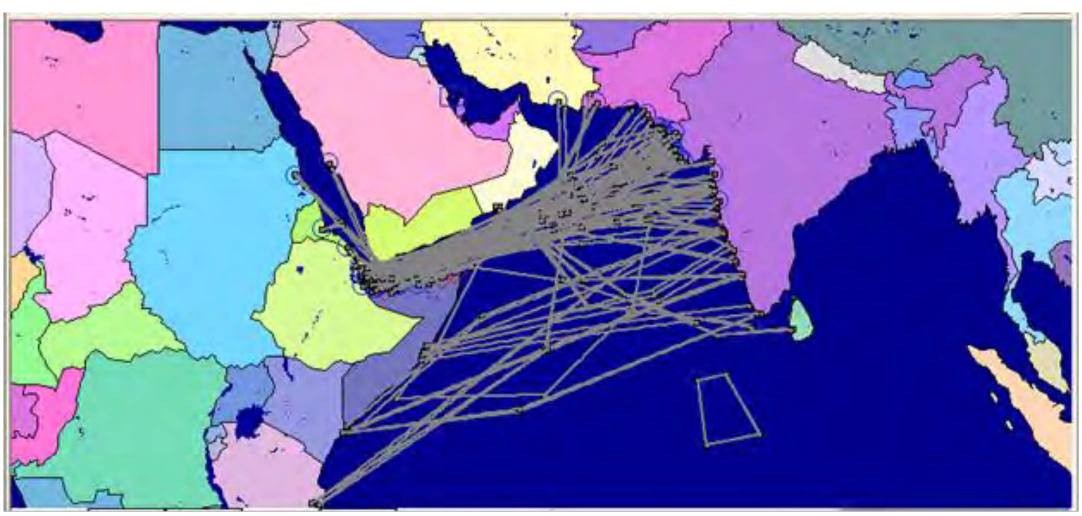


Figure 29. NSS Cargo Track Display.

Table 14 outlines the matrix used to develop objects in modeling scenarios. Scenario development consisted of setting up two separate alliances. Each of the alliances were assigned resources, some of which are shown below. Commanders were assigned to each of the alliances in order to assign alliance tactics, object properties, and movement actions. Individual entity tactics and properties are discussed in further detail in the „Modeling Tactics" section of this chapter.

B. MODEL SCENARIOS

Table 14 outlines the number of ships used for each of the four modeling scenarios. The four modeled scenarios are described in more detail in the following sections. All scenarios had a time frame of a 30 day window to simulate the number of interactions in a single month. The 30 day window was also chosen to decrease NSS server processing time when running multiple replications through the study management mode.

1. Pirates Unopposed (Baseline)

This scenario was the baseline model where the pirates were unopposed and openly attacked merchant vessels without resistance. Container ships were assigned repeating tracks travelling through the corridor of the Gulf of Aden through which ships transit. Originally, 500 cargo ships were to be modeled going back and forth through the gulf, but due to NSS memory limitations, the OARS team was forced to scale this number down to 355. The container ships were assigned an in-and-out track that they would travel, which was straight down the middle of the Gulf of Aden. One hundred pirate motherships and 200 pirate skiffs (two per mothership), were equally divided among five separate but equally sized regions within the 390,000 square miles in the Gulf of Aden. Within each region, 20 red pirate motherships were assigned a patrol movement in which the motherships would actively search for blue container ships to attack. Motherships were given a "visual radar" property to allow them to scan for container ships up to nine miles away, which is reasonable given the size of the ships and the assumption that binoculars may be used. Upon confirmation of container ship sighting

within a nine mile radius, the mothership would launch attack pirate skiffs. When the pirate skiffs arrived at the container ships, the attack would begin and a successful overtake of the container ship being successfully undertaken would be reported when the blue ship was eliminated. This baseline allowed additional follow-on scenarios to be built upon its structure: additionally, it provided a "worst case scenario" number of successful pirate attacks without any opposition from U.S. or allied naval forces. The MOE data was gathered after running the scenario for three replications and then the data was exported to an Excel spreadsheet for analysis.

Table 14. Scenario Objectives and Quantities.

Object Name	Baseline 1 – No Naval Support	Baseline 2 – CTF 151 (Scaled to .39 Million sq. miles)	OARS Alternative 1 – LCS Host Ships	OARS Alternative 2 – LCS Host Ships w/ Air Support
AK Amur Cargo Ships	355	355	355	355
Pirate Motherships	100	100	100	100
Pirate Skiffs	200	200	200	200
SH-60 Helos	0	2	0	0
USN LCS Class Ships	0	0	6	6
USN DDG Arliegh Burke Class Ships	0	2	0	0
USN FFG Perry Class Ships	0	1	0	0
USN LPD San Antonio Class Ships	0	1	0	0
Chinese Jianwei Frigates	0	2	0	0
Korean USLAN Frigates	0	1	0	0
Turkey Barbaros Frigates	0	3	0	0
Singapore Formidable Frigates	0	2	0	0
Canadian Halifax Frigates	0	1	0	0
French Floreal Frigates	0	1	0	0
Dynalifter Hybrid Airships	0	0	0	1
Scan Eagle UAVs	0	2	54	54

2. CTF-151 (Currently Existing Scenario)

This scenario was modeled to simulate the current efforts of the CTF-151 coalition force. CTF-151, as previously explained, consists of U.S. Navy and allied ships working together to combat piracy in the Gulf of Aden. The blue Navy alliance ships that were modeled included a DDG 51 Arleigh-Burke Class destroyer, LPD 17 San Antonio Class Amphibious assault ship, and a FFG Oliver Hazard Perry Class Frigate. Also included in the "Blue" alliance were ten coalition vessels which make up the majority of CTF-151. Coalition vessels included Chinese Frigates (Jianwei Class), Korean Frigates (ULSAN Class), Turkey Frigate (Barbaros Class), Singapore Frigate (Formidable Class), Canadian Frigate (Halifax Class), and French Frigate (Floreal Class) platforms. Though the Chinese Frigates are not strictly part of CTF-151, they are deployed there to protect the commercial interests of the Chinese government and assist with the overall effort to deter piracy. Certain coalition vessels were modeled with SH-60 SeaHawk Helicopter capabilities; these were the Singapore ships and Turkish ships. Coalition vessels that were modeled with UAVs were the Canadian Frigates (SH3D Sea King) and the French Frigate (Z9C Dauphin). Refer to Table 14 above for the exact number of each of the coalition and Navy ships modeled in this scenario. All ships had inherent weapon properties that were adjusted in order to reflect international law that suspected pirates are not to be treated as enemy combatants. Thus all missile launch capabilities and anti-aircraft guns were removed, allowing only small caliber deck machine guns to be utilized. Each ship was assigned a patrol track in each of the six equally sized pirate zones which allowed them to deter and intercept pirates only in their region. All sensor properties were left at the default NSS inherited value. This allowed the ships to detect the presence of motherships and thus, the pirate skiffs. The 100 pirate motherships with accompanying 200 pirate skiffs were carried over from the baseline scenario and modeled identically. SH-60 Helicopters and a limited number of UAVs were added to this scenario to reflect the current limited use of UAVs utilized in CTF-151 presently. UAVs were treated as aircraft objects in the model and therefore the inherent properties of the UAVs were left at default inherited NSS values. Pirate kills were recorded as pirate ships that were overtaken and confirmed through a MOE output

of Red Asset Destroyed. Data was gathered for three scenario replications and automatically exported to a spreadsheet for analysis.

3. LCS Host Vessel with UAVs (OARS Basic)

This scenario was modeled using multiple UAVs to increase the sensor range of the surface ship as well as increase the sensor effectiveness of the blue alliance. This scenario introduced six Littoral Combat Ship (LCS) host vessels and 36 ScanEagle UAVs (6 per LCS) for piracy detection sensors. For an exact breakdown of the number of platforms modeled, please refer to Table 14. All host ship platforms used in NSS had the built in capability to launch and recover multiple UAVs. In this scenario, all of the U.S. Navy ships and coalition vessels were again divided equally among the six piracy zones. All 200 pirate skiffs and 100 motherships left at their previously assigned zones with the red alliance. All blue Navy assets were assigned the same patrol sweeps to look for pirates as in the CTF-151 scenario described above. The UAV that was assigned to launch from all U.S. Navy ships was the ScanEagle with a patrol track within one of the five designated piracy areas. Upon confirmation of a pirate vessel sighting, the UAV would report back to the host vessel and the host vessel would utilize its superior speed and range to attempt to overtake and eliminate the pirate threat. This overtake action was not explicitly shown in the model due to the fact that the action of overtaking a pirate vessel was measured through the Red Asset Destroyed MOE. Though the speed properties assigned to pirate skiffs were greater than all of the U.S. Navy and coalition ships, the craft"s range was limited. For an exact breakdown of derived, assumed, and calculated values for pirate skiffs and motherships, please refer to Appendix C. Once the pirate skiffs returned to the pirate mothership, the speed of the mothership was limited to that of a typical fishing vessel, allowing any one of the blue alliance to overtake and eliminate the threat. Data was gathered from three replications of the scenario and automatically exported to a spreadsheet for analysis.

4. LCS with Air Support Vessel (OARS Augmented)

During the modeling and scenario development for the LCS with Air Support concept, the NSS program database was erased through a Naval Postgraduate School

(NPS) technician"s error. This ultimately wiped out all existing OARS scenarios. This loss of data erased all earlier model development and did not allow the team to complete the scenario listed below. Therefore, this scenario is described purely as an area for further research and future investigation, as there was no output data available.

This scenario was to be modeled identically to the LCS host ship scenario (OARS Basic), with the added support of a hybrid airship to increase the detection range and effectiveness of the blue alliance. The unmanned airship was to be land-based but capable of greater endurance and range to exponentially increase the sensor effectiveness of the alliance. As seen from Table 14, the six LCS class were all to be modeled with associated ScanEagle UAVs. The airship selected for this scenario was the MDL-100X1 Dynalifter. This aircraft was not available in the default database of objects in NSS so an equivalent aircraft was chosen to simulate it as closely as possible. The baseline aircraft for modification to the airship was an E2 Hawkeye. Speed, range, detection capability, and fuel capacity properties were all altered to reflect the MDL-100X1 Dynalifter as closely as possible. The actual detection capability of the MDL-100X1 Dynalifter is extensive, but still not quite as effective as the actual E2 Hawkeye so the sensor capability property was adjusted. As in previous scenarios the blue alliance ships were divided between the five zones along with their accompanying UAV squadrons. One "MDL-100X1 Dynalifter" was assigned to this scenario and its path was a racetrack path around the entire Gulf of Aden operating area. This scenario was fully modeled, but because of the deletion of the NSS database, no outputs could be measured.

C. MODELING PARAMETERS

Modeling tactics were based on assignable tactics table actions available within NSS. The tactics essentially dictated how the model object would react when presented with an opposing asset object. NSS allowed multiple behaviors to be simulated concurrently in order to best represent real-world actions of surface ships, UAVs, and helicopters. By manipulating the behaviors and operating rules for each asset, different scenarios could be customized to suit the needs of each individual alternative. For a

complete list of the individual object tactics and their associated responses, please refer to Table 15.

Table 15. Modeling Tactics by Platform.

Platform	Tactic	Tactic Description
Pirate Skiffs	Attack/Avoid Air Tactic	Attacks blue cargo vessels but avoids UAVS or Naval vessels when detected
Cargo ships	Report All Tactic	Reports pirate attacks back to the "cargo base" to spread the word to other cargo ships
Naval Vessels	Anti-Piracy Tactic	Attacks red vessels in range of weapons and also includes a reporting aspect to share piracy detection information with the coalition forces
Pirate Motherships	Avoid Air Tactic	Avoids UAVS or Naval vessels when detected
UAV's	Report All Tactic	Reports aerial information back to the naval commander about asset detections and classifications (blue or red asset) to spread information to the other coalition forces
Airship	Report All Tactic	Reports aerial information back to the naval commander about asset detections and classifications (blue or red asset) to spread information to the other coalition forces

Interaction tables were also used to set up the effectiveness of weapons against different classes of ships. For example, small deck weapons on the blue assets were given a probability of hit (Ph) of around 0.8 for the larger pirate motherships, and a lower Ph of around 0.4 for the smaller pirate skiffs. Additionally, the pirate skiffs were set to be un-attackable with larger weapons, such as harpoons, which would essentially be ineffective in a real world scenario. All the missile capabilities and large scale weapons of the blue alliance were considered unrealistic in the model and also not allowed by international law for use against suspected pirates. Due to this reason, the P_h of all large weapon and missile capabilities were set to zero.

Mission plans were another aspect of the NSS modeling that applied to UAV launches and pirate skiff launches. In order for the surface ships (either alliance) to launch a secondary craft, mission plans needed to be defined in order to specify the timing and launch conditions. UAVs were launched off of all surface craft in regular intervals, with a rotating pool of assets to keep a 24 hour surveillance window. LCS

ships had a larger pool of 9 UAV assets (versus other naval surface ships) in order to improve availability within the operating zone. Pirate skiffs were launched from the mothership upon detection of a cargo ship to initiate an attack, and recalled to the mothership upon detection of an opposing blue force UAV or surface ship.

Model objects were also assigned specified motion parameters in order to initiate realistic interactions in the scenarios. The motion of each asset is described in Table 16 below.

Table 16. Asset Motion.

Asset Type	Motion Type	Motion Description
Blue Cargo Ship	Track	355 cargo ships were assigned fixed motion tracks across the Gulf of Aden and travelled a repeating path back and forth.
Red Pirate Motherships	Area Patrol	Five separate pirate operating areas were established throughout the Gulf of Aden and 20 pirate motherships were confined to patrol each area using the default NSS "patrol" function.
Blue Navy & Coalition Ships	Area Patrol	Five separate pirate operating areas were established throughout the Gulf of Aden and all available blue assets were spread across the operating areas in order to patrol for red assets using the default NSS "patrol" function.
Blue UAVs and helicopters	Area Patrol/Detect	Mission plans were used to launch all aerial vehicles and the vehicles used the default NSS aerial "patrol" function to detect and classify all assets.
Red Pirate Skiffs (modeled as aerial vehicles due to NSS constraints)	Area Patrol	Mission plans were used to launch the pirate skiffs and the skiffs used the default aerial "patrol" function to attack blue cargo assets.

D. RESULTS

Because of the inadvertent loss of the NSS database during scenario development, only limited data for three out of the four scenarios is available in this section. The results shown below in Table 17, MOE Outputs, indicate that there were no large discernible differences between the effectiveness of the Basic OARS system and the current CTF-151 solution. The major difference that the model did indicate was that there were 130,379 UAV detections compared to CTF-151's 91,179. This is due to the fact that the OARS system had 875 launches, and CTF-151 only had 277.

CTF-151 had more pirate arrests (overtakes) than the OARS system, but the OARS system used its UAV presence to deter pirates from attacking. An “aircraft avoid tactic” was built into all red assets in the NSS models. This meant that the modeled pirates would be less likely to commit acts of piracy if they spotted the surveillance UAVs overhead. Due to this aspect of the model, the fact that the OARS system lowered the amount of piracy attempts was an expected outcome. Additionally, the OARS system was slightly more effective in combating pirate motherships in terms of the overtake percentage MOE, but again, the system utilizes newer, more effective LCS ships with better weapons, and depends more on UAV presence to deter piracy.

One of the major MOEs for this system is “percentage detection measurement.” OARS performed well in this area with an overall average number of detections at 130,379 versus 91,171 in the CTF-151 scenario. This indicates that further research into the area of aerial long range sensors (such as those on the hybrid airship in the OARS Augmented scenario) should be conducted in the future to enhance anti-piracy efforts. The presence of a UAV in hostile ocean areas appears to be a simple deterrence method to combat piracy. Empirical, quantitative, research methods need to be employed in the field to further test and validate the effectiveness of this deterrence method.

Table 17. MOE Outputs by Scenario and MOE.

Unopposed Baseline (3 replications)	
MOE name	**Average**
Red Assets Destroyed (Overtaken)	0
Blue Assets Destroyed (Overtaken)	57.7
Red Weapon Launches (Overtake Attempts)	123
Blue Weapon Launches (Overtake Attempts)	0
CTF 151 (3 replications)	
MOE name	**Average**
Red Assets Destroyed (Overtaken)	9.3
Blue Assets Destroyed (Overtaken)	30.0
Red Weapon Launches (Overtake Attempts)	87.3
Blue Weapon Launches (Overtake Attempts)	27.7
Blue Surveillance Classifications	9937
UAV Cumulative Launches	277.3
Blue Surveillance Detections	91179.7
Red Successful Overtake % (Derived MOE)	34.3%
Blue Successful Overtake % (Derived MOE)	32.5%
OARS BASIC (3 replications)	
MOE name	**Average**
Red Assets Destroyed (Overtaken)	3
Blue Assets Destroyed (Overtaken)	27.3
Red Weapon Launches (Overtake Attempts)	82.0
Blue Weapon Launches (Overtake Attempts)	6.7
Blue Surveillance Classifications	49223
UAV Cumulative Launches	875
Blue Surveillance Detections	130379.3
Red Successful Overtake % (Derived MOE)	32.4%
Blue Successful Overtake % (Derived MOE)	45.0%

E. MODEL LIMITATIONS

Some limitations associated with the NSS software constrained the team‟s ability to simulate the OARS concept in a realistic manner. One limitation associated with the NSS software was that entering new MOEs into the system instead of utilizing the ones that were already built into the program was a very complex process. This drove the team to select measurements under default classes available within NSS such as asset destruction, weapon launches, UAV launches, sensor classifications, and sensor detections. These measurements fit well with the stated systems engineering process, so

restrictions on MOE data was not a big issue. Future studies in the area of anti-piracy systems may elect to customize NSS MOE outputs to better tailor them to the project requirements.

The NSS software is based on traditional naval warfare interactions between known enemies, and therefore is not always flexible in adapting to a non-traditional and evasive enemy like pirates. Since the pirates often use evasive tactics such as disguising the motherships as fishing boats, the blue asset detection characteristics were difficult to model realistically. Often in the scenario, a blue force asset would be immediately aware that a red enemy force is nearby through the use of detection sensors, while in real life, the pirate assets are difficult to identify because they mix in so well with normal merchant traffic. This issue was somewhat mitigated by using a timed hostile action flag. Blue vessels were not allowed to engage pirate vessels unless a hostile action had taken place within a set amount of time. This feature simulated the ability of the pirates to blend back into the background traffic if they were not engaged quickly.

Cargo/container ships were difficult to model within the scenarios because of the sheer number of transport ships that operate in the Gulf of Aden. Exact paths for ships were difficult to model because of the variability within shipping origin ports and destinations. Therefore, the modeling team chose to simulate 1000 ship crossings over the course of a month by utilizing 500 blue cargo vessels on a continuous back and forth loop in areas known to have the most piracy. The actual number of blue cargo vessels was finalized at 355 assets because of NSS memory constraints, but the team has reasonable assurance that at least 1000 crossings were made over the course of 30 days in all four scenarios (since each scenario had at least 3 crossings through the Gulf of Aden by each cargo ship).

Other limitations included a limited number of baseline platforms in the NSS database, especially when it came to new classes of surface ships and UAVs. This meant that many existing platforms had to be extensively modified in order to fit the operating parameters of the new platforms like the LCS, Dynalifter Hybrid Airship, and ScanEagle UAV. Major modifications to the ship object properties were often time consuming and many times led to NSS software run errors when scenarios would be replicated.

Refinement of the new object properties was a continual process in order to ensure that the NSS simulations ran smoothly.

Furthermore, some surface assets, such as pirate skiffs, needed to be modeled as aerial assets due to NSS constraints of only being unable to launch surface craft from surface ships. This had little effect on the interactions within the model, since the pirate skiffs were simply modeled as UAVs with an elevation of zero and the ability to attack cargo ships.

In conclusion, although there were limitations to the NSS software, the OARS team was able to produce three separate scenarios which were effective in depicting the important parameters and measuring the MOEs related to real-world piracy interactions. The NSS software package was only partially capable of modeling the real world piracy interactions, and it was instead designed more for traditional warfare between two known enemies. Due to this, a more flexible software package may be required in the future, if research is continued in the area of anti-piracy.

F. COST ANALYSIS

Each OARS alternative is comprised of subsystems that need to be initially procured from existing programs. Costs were derived from published documents found from the respective program research. Initial costs include the current market costs of each alternative system with the correct inflation indices applied. Procurement of future alternatives to replace that item is done through the acquisition strategy using an incremental, technical refresh process. The initial procurement costs account for the majority of funding for each system.

Future year spending provides a method of determining where and when funding should be applied. Inflation rates have been used to establish out year costs, and expected costs are in FY11 dollars. Procurement dollars for each OARS alternative decline dramatically after the first two years due to the fact that the systems will be fully acquired. Additional procurement dollars will be needed later in the OARS alternative‟s life cycles due to the planned acquisition of new technology during the technology refresh periods.

1. Cost Assumptions

Due to the fact that the OARS alternative systems have not been developed or operated in a combat environment, the procurement, operations, and support costs are not yet documented for analysis. As a result, all cost analysis focused exclusively on the individual subsystems within the OARS alternatives that would be deployed in a typical anti-piracy mission.

Exhaustive research was conducted to find a Subject Matter Expert (SME) or credible source for each OARS subsystem. Data collection consisted of a comprehensive research effort spanning various Navy organizations as well as non-military organizations. The data collected was comprised of pertinent information that was unclassified and available to the public. Actual costs, SME input, confirmed specifications, and best effort estimates, provided inputs to the OARS cost models. By finding the SMEs for each subsystem, more accurate estimates of subsystem costs were made. Additional research provided unit prices and system specifications (including size, weight, and speed), as well as capability estimates based on current systems of record. The SMEs were able to either provide documentation for exact costs and system specifications, or at least a rough estimate for the respective system. Unknown variables, such as integration costs, were given best effort analyses to determine reasonable cost ranges on existing systems of record.

During the modeling and simulation phase of the project, the OARS team assumed that UAVs would be utilized for only detection and surveillance. It was assumed that detection of the UAVs‟s presence by the pirates would induce them to halt their aggression. For this reason, the cost calculations did not include weapon systems aboard the UAV; rather, the weapon system cost was added to the pursuit vessels in the form of mounted .50 caliber machine guns. Complete UAV system Life Cycle Costs (LCC) would normally be critical to the cost comparisons of each system‟s LCCs; however, through UAV cost research, the OARS team obtained limited data which consists of an hour-by-hour cost comparison for each of the airborne sensors. The calculated cost of UAV support was derived from a variety of sources that are documented in the references section. Parametric estimates suggest that there would be

six UAVs aboard each host vessel, with three flying at all times. This would allow an "around the clock" detection capability. The OARS team found that for every flight-hour that each UAV was flown, there would be a corresponding operating cost of approximately $100 per-vehicle (Defense, Space & Security 2011).

The sub-systems of each OARS alternative focused on existing mature technology and the strategies that have been adopted to support those technologies. The fielding of these mature systems allows the OARS system to leverage the existing U.S. Navy supply and maintenance infrastructure. It also simplifies the components of training and helps facilitate the roles of both the Technical Design Agents (TDA) and the In-Service Engineering Agents (ISEA).

Specific consumables and non-lethal interdiction aids were not included in the cost assessment as they are procured as a result of specific threats and provided to system operators to carry as a payload. The costs associated with training personnel to operate weapon systems and sensor packages were included in our analysis. Consumables like ammunition, dye markers, smoke markers, and smoke-screen bombs used during training scenarios were included in the life cycle costs as a component of integration and disposal.

a. Life Cycle Costs

The total cost of each alternative over their expected lifetime was determined through a Life Cycle Cost (LCC) analysis. It provides an estimate of how much funding would be required per year to ensure the alternative is fully operational. The entire profile of the LCC was categorized in six different costs. These costs are: procurement, integration, logistics, operation, maintenance, and disposal. Both alternatives had an individual LCC profile that was examined in further detail below.

The length of each OARS alternative‟s life cycle was a result of several underlying factors. The entire life cycle can be broken down into two phases with the first phase seen as the system‟s acquisition. This depends on how quickly the assets can be procured and integrated, as well as how much funding will be logically appropriate during that time period. The second phase was the actual operational life cycle of the

systems. This includes the logistics, operation, maintenance, and disposal costs associated with fielding the systems. During each year of the life cycle it was assumed that there will be on average 365 missions per year with 24 hour, unceasing service on each mission day. The life of the system was evaluated based upon the lifecycles of the corresponding subsystems. The mature elements that are weaved into the OARS system supported the 15 year fielding plan with technical refresher cycles to be planned in 2025 and 2030. The end of life for both alternative systems is expected to be 2035.

2. Cost Analysis and System Specification Methodology

The rendered alternatives that were deemed feasible were given a comparative cost benefit analysis to determine how much capability could be provided and at what cost. The cost of each alternative was examined from multiple perspectives. Unit price, estimated integration costs, manpower costs, and many other cost components were used to determine relative alternative costs.

Spreadsheet tools were used to capture system data and analyze both mathematically and graphically the relationships and relative costs between system alternatives. The costs were categorized as procurement costs and life cycle costs. The costs of the two OARS alternatives were also broken out by their corresponding functional objectives. This data can be found in Appendix I.

In order to generate a cost estimate for a single alternative, the cumulative costs of the subsystems were accounted for as accurately as possible. A 15 year life cycle cost (LCC) analysis was performed for each of the two OARS alternatives. A spiral and incremental procurement strategy was employed and included as an acquisition cost category for the LCC analysis. In 2025 and 2030, an incremental technical refresh was scheduled to occur in order to make the OARS lifecycle more realistic.

a. Preferential Model Results

Each alternative component (element) was selected by using a multiple criteria preference model. Each objective was broken down into key attributes by stakeholder preferences. The preference model can be found in Appendix G.

The result is that the Zodiac Rigid Hull Inflatable Boat (RHIB) was the best alternative to use in both of the OARS systems. Similarly, the same technique was also utilized for evaluating what the best lightweight UAV would be. These lightweight UAVs were to be used for surveillance in both OARS alternatives. The model resulted in the ScanEagle UAV arising as the most preferred, mostly due to its very long endurance and range. A preferential model was also developed for the Heavy UAV BAMS system that was to be used in the Augmented OARS alternative. This resulted in the MQ-4 Global Hawk being chosen as the best BAMS alternative to model in the Augmented OARS cost analysis.

3. Cost of Alternative #1, Basic OARS

a. Procurement Costs

The total procurement cost of Alternative 1, Basic OARS, was found to be \$4.78 billion. Costs for Alternative 1, Basic OARS, include funding for combat systems, air-borne sensor packages, surface sensors, and weapon systems. Combat systems include command and control consoles, as well as communication devices. Table 18 shows Alternative 1"s procurement cost breakdown. The data shows that the bulk of Alternative 1"s procurement costs center around its use of six individual Littoral Combat Ships (LCS) systems.

Table 18. Procurement Cost Breakdown for Alternative 1.

Item	Acquisition in \$ Millions	Percent of Total
Host Vessels: LCS Ships	\$ 4,080.00	88.83%
UAV's	\$ 1.32	0.03%
SH-60s	\$ 509.00	11.08%
Pursuit Vessels: RHIBs	\$ 0.90	0.02%
50 Cal MG	\$ 2.03	0.04%

Total Acquisition	**\$ 4,593.25**

b. Life Cycle Costs

Table 19 illustrates a similar table that highlights the total LCC of Alternative 1. The total LCC of Alternative 1 comes to \$15.5 billion. Similar to the procurement numbers, the LCS ships and SH-60 Helicopters account for the majority of the LCC for Alternative 1.

Table 19. LCC Breakdown for Alternative 1.

Item	LCC in \$ Millions		Percent of Total
Host Vessels: LCS Ships	\$	7,980.00	51.45%
UAV's	\$	773.43	4.99%
SH-60s	\$	6,048.30	39.00%
Pursuit Vessels: RHIBs	\$	704.97	4.55%
50 Cal MG	\$	2.54	0.02%

Total LCC	**\$**	**15,509.23**

Figure 30 illustrates a breakdown of the total LCC of each of Alternatives 1‟s subsystems. As noted previously, the LCS and SH-60 Helicopter systems account for the majority of the costs.

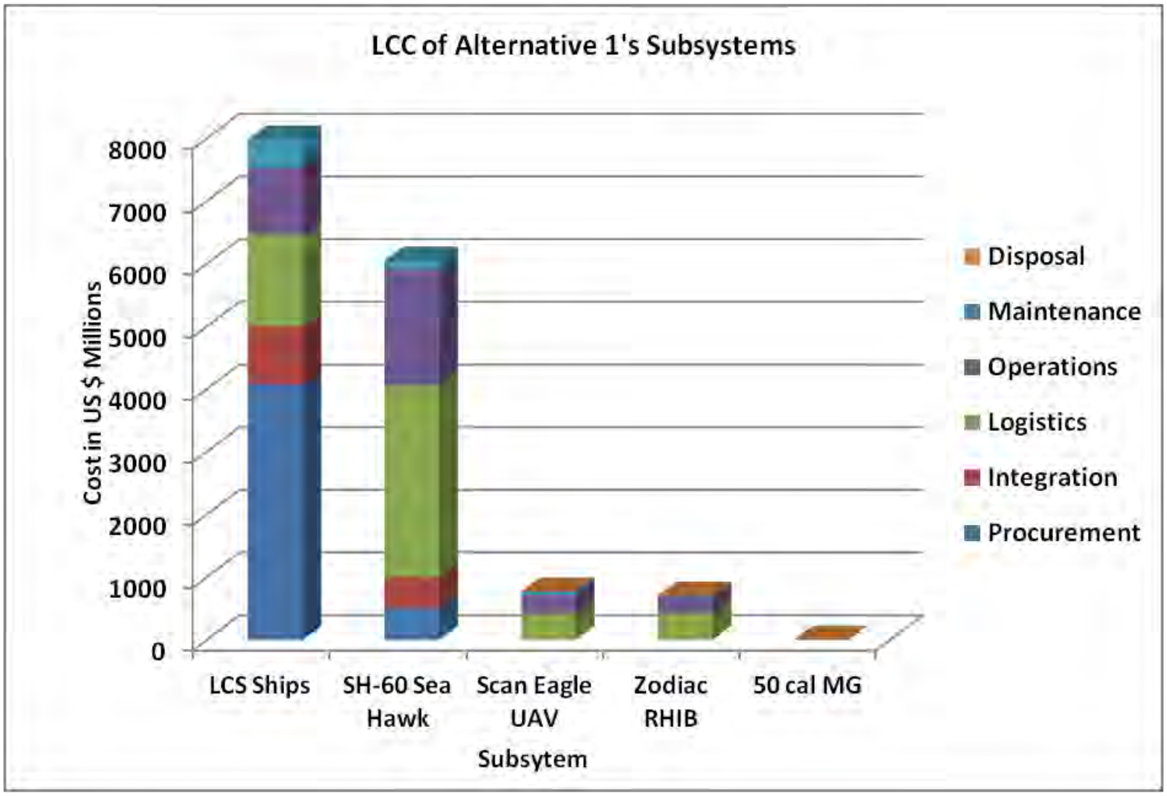


Figure 30. LCC Breakdown of Alternative 1‟s Subsystems.

Figure 31 shows the funding cycle of Alternative 1‟s life cycle. The figure shows an initial spike in funding with a gradual increase of funding throughout the fielding process. The acquisition phase will take place within the first five years. The largest amount of funding throughout the entire life cycle will come during the second year with nearly $2.591 billion appropriated towards 23% of the total initial procurement costs and 20.5% of the initial integration costs.

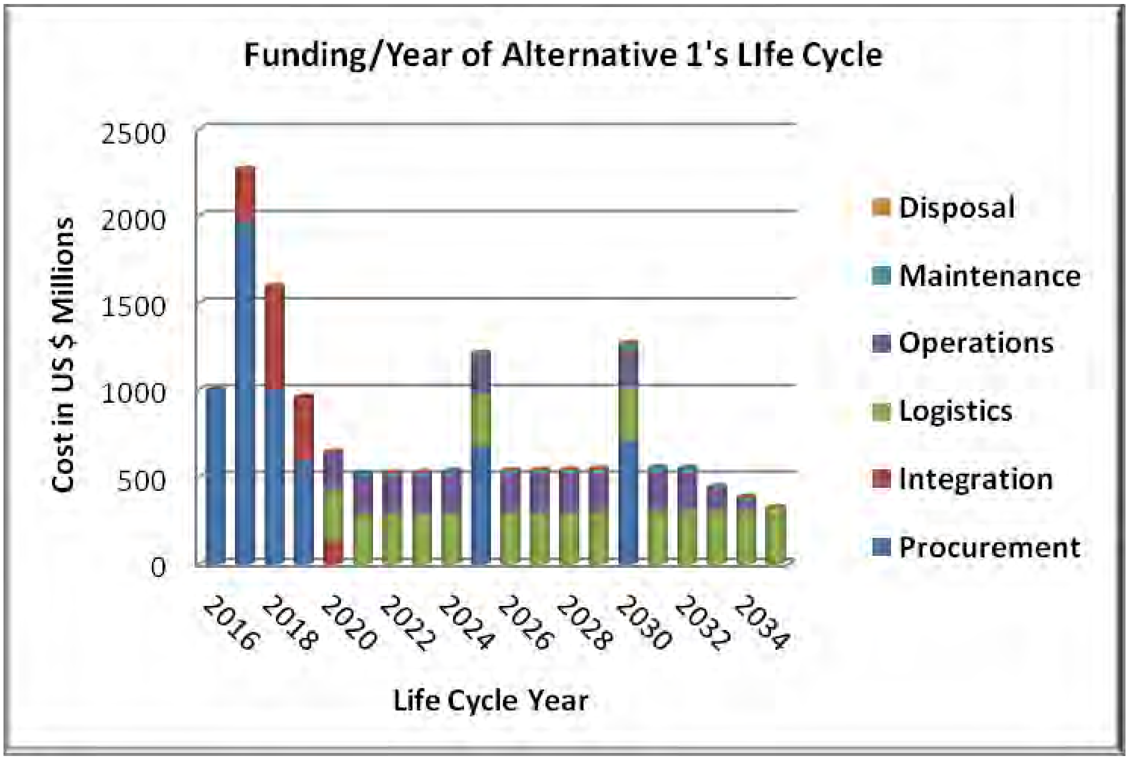


Figure 31. LCC of Alternative 1.

The fielding phase will begin in year 2020 with approximately $440 million appropriated to logistics, maintenance, and operational costs. Each year beyond that, costs in each area will gradually increase until 2032 with a total cost just over $450 million. The subsequent year will see a decrease in operational costs due to a reduction in training needs. The year 2033 will be the first year that maintenance costs are cut, but it will also be the first year that disposal costs are applied. The final year will consist solely of disposal and logistics costs. Throughout the entire fielding phase of the life cycle, the logistics costs will increase at a constant rate.

The two additional funding spikes that are shown in Figure 31 will come during the technical refresh installments, which were planned to occur in 2025 and 2030. Nearly $500 million in technical refresh costs will be spent in the first technical refresh period of 2025. Similarly, almost $620 million will be spent during the second technical refresh year of 2030.

Costs for the acquisition phase and fielding phase in Alternative 1 are quite similar even though one phase is five years and the other is 15 years. A distribution of cost categories for LCC is displayed on Figure 32. The figure shows that the acquisition phase represents 39% of the total costs while the cost for the fielding phase accounts for the remaining 61%. Initial procurement and the procurement for the technical refresh integration is the largest cost, at nearly $4.8 billion. Logistics makes up exactly one third of the total cost with almost $3.6 billion allocated towards it. The integration portion is set at 9% which accounts for $730 Million. This correlates well with legacy integration efforts utilized during the 10 year development of technology upgrades for the Apollo project. This integration effort has been well documented by NASA and this data was utilized by the OARS team to help define integration costs of the OARS system (National Aeronautics and Space Administration 2011, 678).

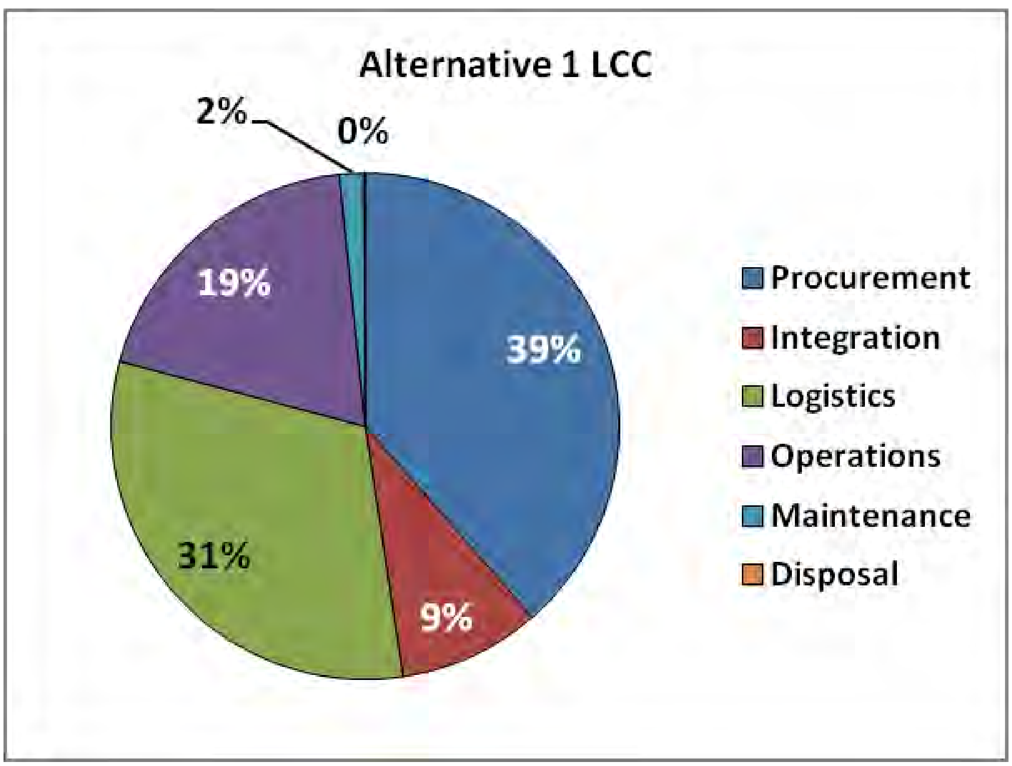


Figure 32. Alternative 1 LCC.

The OARS team determined that the requirements for manning the system will consist of utilizing 45 sailors per watch shift. Furthermore, it is assumed that there will be three separate watch shifts, each consisting of 8 hour periods (Douangaphaivong 2004, pg 60). The maintenance and disposal costs are relatively minor compared to the other four cost categories, but still need to be considered when determining the overall LCC.

4. Cost of Alternative #2, Augmented OARS

a. Procurement Costs

A procurement cost breakdown for Alternative 2 is shown in Table 20. The table shows that Alternative 2‟s procurement cost is roughly $5 billion. Just as with Alternative 1, Alternative 2‟s total funding amount is largely affected by the procurement cost of the host ship platforms. However, the addition of Alternative 2‟s BAMS system increases the procurement cost.

Table 20. Procurement Cost Breakdown of Alternative 2

Item	Acquisition in $ Millions	Percent of Total
Host Vessels: LCS Ship	$ 4,080.00	81.06%
UAV's	$ 1.32	0.03%
SH-60	$ 509.00	10.11%
Pursuit Vessels: RHIBs	$ 0.90	0.02%
50 Cal MG	$ 2.03	0.04%
BAMS	$ 440.00	8.74%
Total Acquisition	**$ 5,033.25**	

b. Life Cycle Costs

The breakdown of Alternative 2‟s LCC is shown in Table 21. The data shows that Alternative 2‟s LCC estimated at just under $17.7 Billion.

Table 21. LCC Cost Breakdown of Alternative 2.

Item	LCC in $ Millions	Percent of Total
Host Vessels: LCS Ships	$ 7,980.00	44.90%
UAV's	$ 773.43	4.35%
SH-60s	$ 6,048.00	34.03%
Pursuit Vessels: RHIBs	$ 704.97	3.97%
50 Cal MG	$ 2.54	0.01%
BAMS UAV	$ 2,262.00	12.73%
Total LCC	**$ 17,770.93**	

A breakdown of costs for each year of Alternative 2 life cycle is shown in Figure 33. The second and third years of the acquisition phase account for the two largest funding years during the life cycle of the system. Allocation of funding in 2017 will come to just over $2.03 billion, while costs in 2018 will come to just over $1.35 billion. The fielding phase will begin in year 2020, with $429 million appropriated to logistics, maintenance and operational costs. Each year beyond that, costs in each area will gradually increase until 2032, which has a total cost just over $497.5 million. The subsequent year will see a decrease in operational costs due to a reduction in training needs. The year 2033 will be the first year that maintenance costs are cut, but it will also be the first year that disposal costs are applied. The final year will consist solely of disposal and logistics costs. Throughout the entire fielding phase of the life cycle, the logistics costs increase at a constant rate.

The two additional funding spikes that are shown in Figure 33 will come during the technical refresh installments. Nearly $599 million in technical refresh costs will be spent in 2025, which is the first year of installation, and almost $824 million will be spent during the second installation year of 2030.

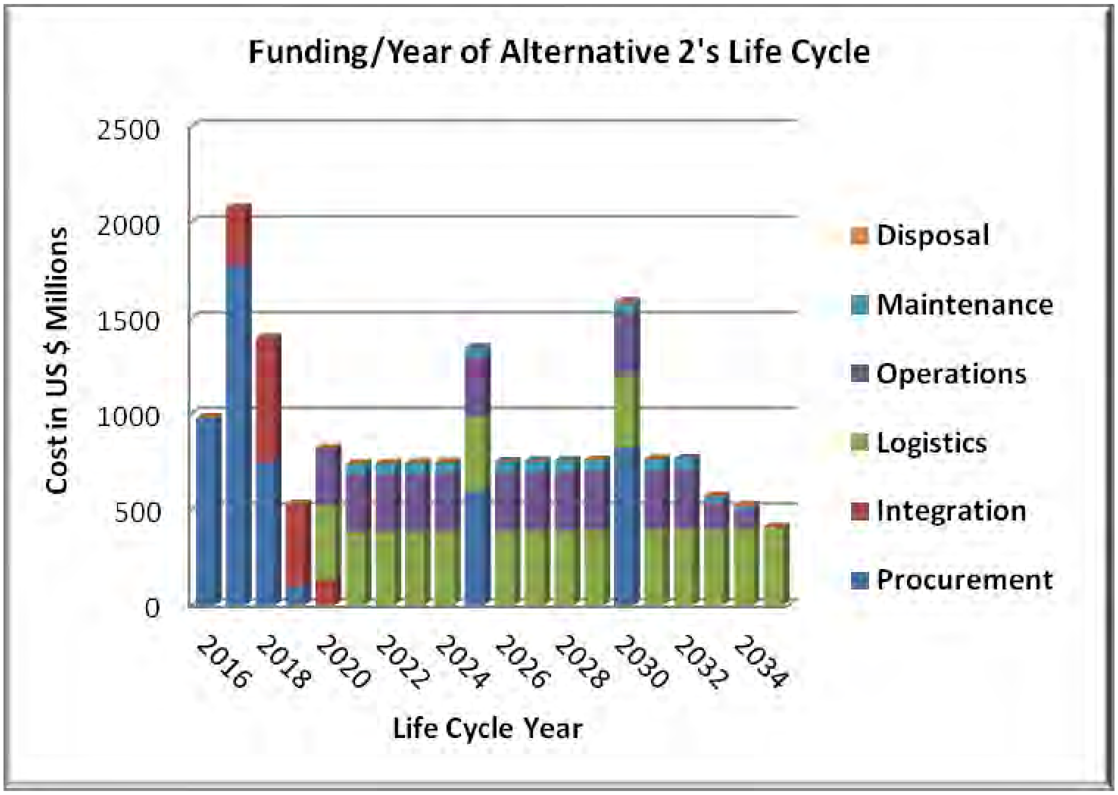


Figure 33. LCC of Alternative 2.

Figure 34 shows a breakdown of Alternative 2"s LCC per each of its subsystems. The data shows that the majority of the LCCs center around the LCS ships and the SH-60 Helicopters, although the introduction of the BAMS UAV adds $2.262 Billion to the LCC that was not a part of Alternative 1.

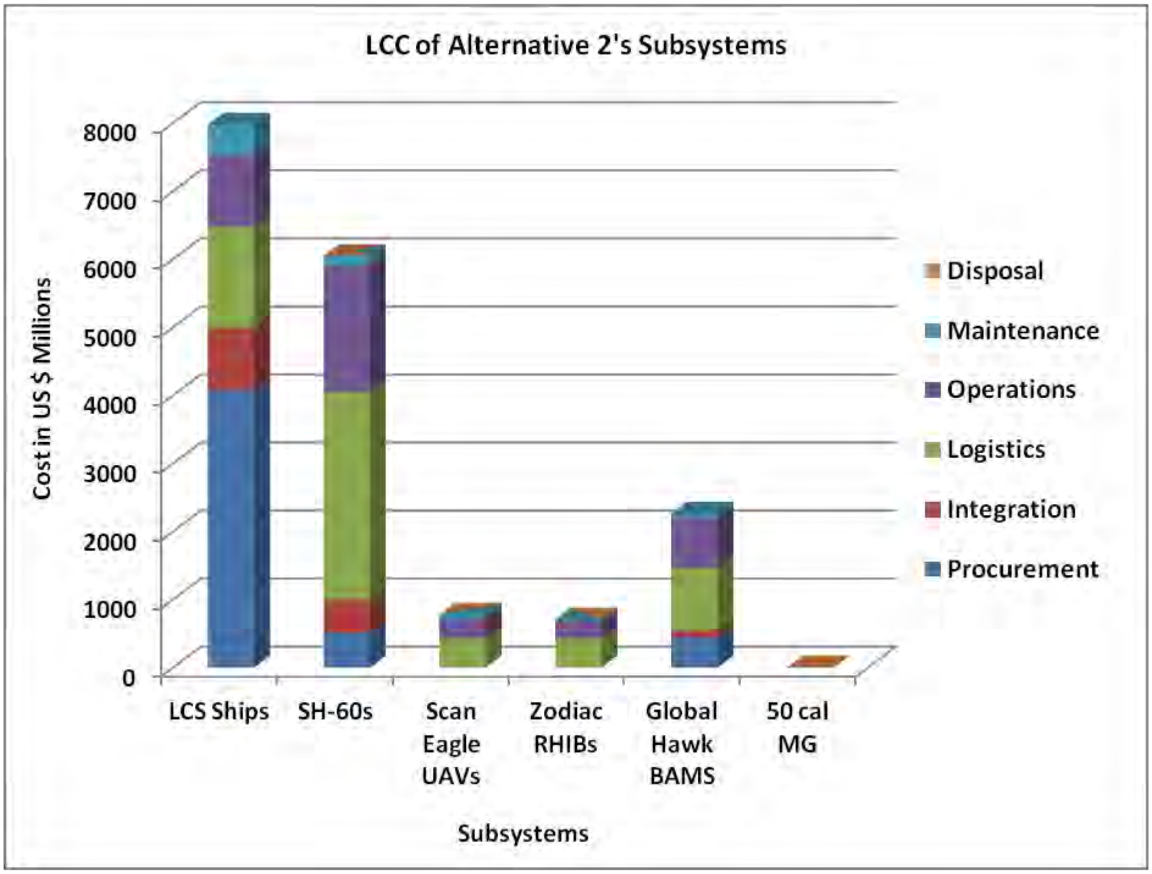


Figure 34. LCC Breakdown of Alternative 2"s Subsystems.

A distribution of cost categories for Alternative 2"s LCC is displayed on Figure 35. The acquisition phase represents 39% of the total LCC cost while the cost for the fielding phase accounts for the remaining 61%.

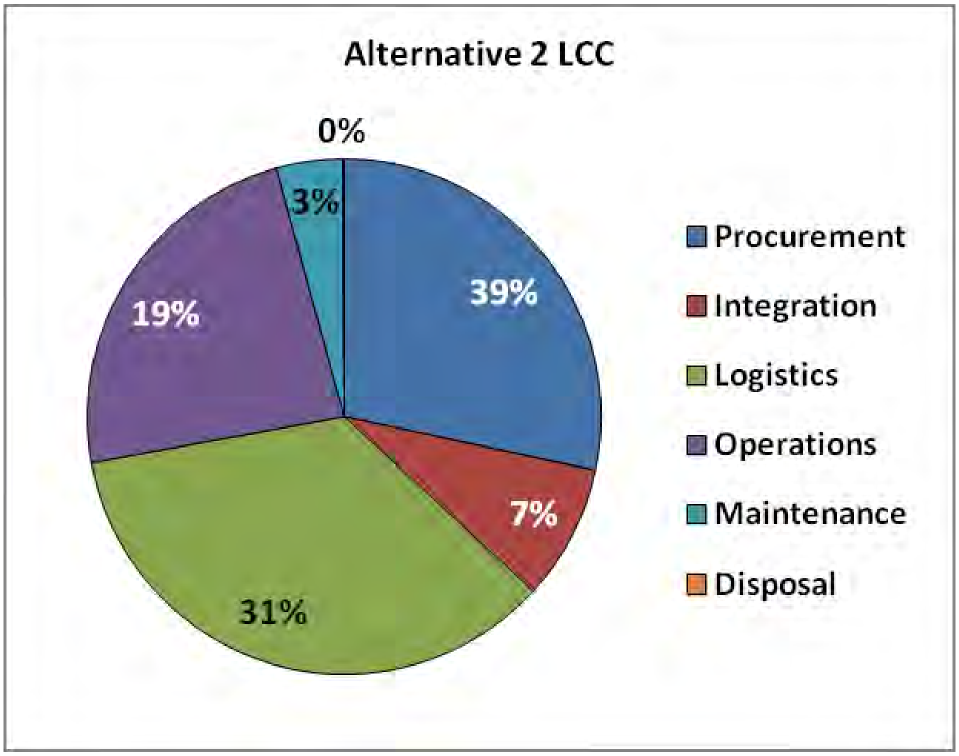


Figure 35. Alternative 2 LCC.

5. Cost of the Status Quo, CTF-151

Defining the exact cost of operating CTF-151 was a very challenging task for the OARS team. The main issue is that the force structure of CTF-151 fluctuates constantly. CTF-151 has matured over its 2 years of operation, but there still is not a baseline force structure to have as a point of reference. CTF-151 is a voluntary force comprised of many countries that provide ships, aircraft, and support in anti-piracy operations when they can. In order to predict the LCC of CTF-151, one would have to know the exact number of ships at any point in time. After performing a great deal of research and talking with stakeholders, the OARS" modeling and simulation team decided to model CTF-151 as containing 14 ships. Four of the ships were assumed to be USN assets. The four U.S. Naval forces were modeled as:

- DDG-51 Destroyer
- FFG-7 Frigate (Quantity – 2)
- LPD-17 Amphibious Transport Dock.

CTF-151‟s ten remaining coalition vessels were assumed to consist of the following ships:

- Jianwei frigate from PRC (China) (Quantity – 2)
- Ulsan frigate from South Korea
- Barbaros frigate from Turkey (Quantity – 3)
- La Fayette frigate from Singpore (Quantity – 2)
- Iroquois destroyer from Canada
- Floreal frigate from France.

In order to be consistent with the modeling and simulation effort, the cost analysis also used this same force structure when estimating the LCC of CTF-151.

Another reason that estimating the cost of CTF-151 is difficult is the fact that most of the assigned ships are from foreign navies and therefore, data on their life cycle costs is not readily available. For this reason, the OARS team utilized the same life cycle costs that were used in the cost estimation efforts of the two OARS alternatives. These life cycle costs were for USN assets, but due to the fact that the foreign navy ships have similar sizes and anti-piracy missions, the assumption was made that the foreign ships would have similar LCCs.

Table 22 shows a breakdown of the estimated LCC of CTF-151. The appropriate number of helicopters, RHIB boats, and the occasional UAVs were also added to the CTF-151‟s LCC model. The LCCs of the helicopters were for USN SH-60 Helicopters. The OARS team made the assumption that the LCCs of foreign helicopters would be similar to the known USN figures. The total LCC was estimated at $17.47 Billion.

Table 22. CTF-151 LCC Cost Analysis.

CTF-151 Ship	Qty	Cost per Ship ($B)	Total Acquisition cost ($B)	Added Item LCC Costs (RHIB, UAV, Helo) ($B)	Total LCC ($M)
DDG-51	1	$1.5050	$1.5050	$0.0882	$3,084.59
FFG-7	2	$0.6710	$1.3420	$0.0008	$3,042.00
LPD-17#	1	$1.2050	$1.2050	$0.0002	$1,649.44
Jianwei	2	$0.1540	$0.3080	$0.0008	$697.00
Ulsan	1	$0.1190	$0.1190	$0.0002	$134.70
Barbaros	3	$1.0140	$3.0420	$0.0272	$5,901.48
La Fayette	2	$0.3100	$0.6200	$0.0178	$1,421.31
Iroquois	1	$1.1590	$1.1590	$0.0119	$1,323.12
Floreal	1	$0.1860	$0.1860	$0.0122	$223.97

Total Acquisition Cost	**$9,645.28**
Total CTF-151 LCC	**$17,477.61**

G. ALTERNATIVE COMPARISON

1. LCC Comparison

Figure 36 shows a life cycle cost comparison of both the OARS alternatives and CTF-151. CTF-151 was estimated to have the highest life cycle cost. Alternative 1, OARS Basic, was estimated to have the lowest LCC. Due to Alternative 2‟s addition of a heavyweight BAMS UAV, its life cycle cost was greater than Alternative 1.

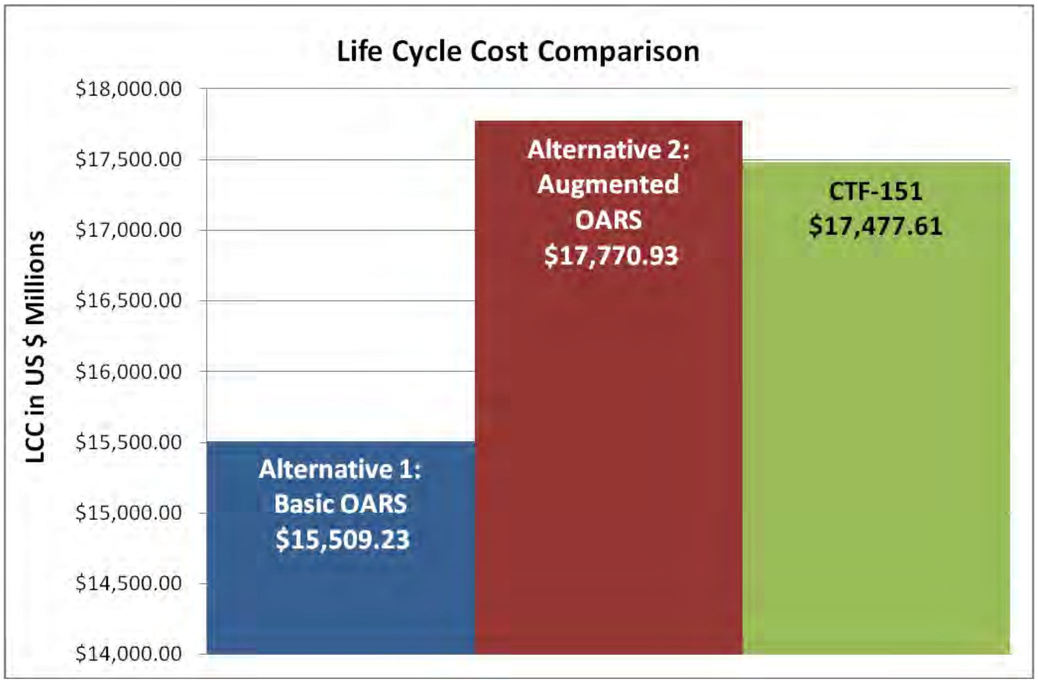


Figure 36. Life Cycle Cost Comparison

2. Cost-Value Analysis

a. Decision Matrix

A decision matrix was used to combine value scores, global weights, and raw data and produce total value scores for each alternative based on the most basic additive form, or weighted summation, of the value function Multi-Attribute Value Theory. In the additive form, the function (U) is split into several different functions (Ui) which are strictly increasing real functions. The function (U) can then be retrieved by adding the sub-functions (Ui). Global weights were derived from Figure 12 of the QFD analysis which states objectives for the system. However, since modeling outputs from NSS did not match up exactly to the QFD outputs, estimates were made for global weights that best matched up to the objective outputs of Figure 12. These global weights were then outlined in Table 23. The measures in the right hand column of the matrix were pulled from the NSS modeling MOE outputs. The OARS Augmented system was not included in this decision matrix because there were no NSS MOE outputs available to analyze.

Table 23. Decision Matrix.

Measure	Global Weight	Alternatives		
		Unopposed	CTF 151	OARS Basic
UAV Total Detections	0.3	0	0.7	1
UAV Total Classifications	0.3	0	0.2	1
UAV Cumulative Launches	0.1	0	0.32	1
Blue Assets Overtaken	0.25	0	0.93	1
Red Assets Overtaken	0.05	0	1	0.34
Total Value Score	**1**	**0**	**0.58**	**0.96**

As seen above, the OARS Basic ranks highest with a Total Value Score of 0.96. CTF 151 has the second highest total value score of 0.58. Since the OARS Basic system scores higher than CTF 151 in four out of the five measures of effectiveness (MOEs) it was determined that no sensitivity analysis was required. The goal of both CTF 151 and OARS is to deter piracy, so overtaking (red) pirate ships will never be assigned a global weight high enough to greatly influence the CTF 151 Total Value Score.

b. Cost versus Value

Cost-value analysis was performed to consider the overall value, with respect to effectiveness. By plotting the total value score obtained from the decision matrix in Table 23 against the system acquisition costs from the cost analysis, relationships between cost and performance can be derived from the alternatives. When an alternative has a higher overall cost and a lower total value score than another alternative it is considered "dominated" by that alternative. The OARS Augments system was not included in this analysis because the purpose of the analysis was only to compare alternatives with available M&S MOE outputs.

Table 24. Cost versus Effectiveness Data.

Alternative	LCC Cost (US $ billions)	Total Value Score
Unopposed	$0.00	0
CTF 151	$17,477.61	0.58
Alternative 1: OARS Basic	$15,509.23	0.96
Alternative 2: OARS Augmented	$17,770.93	Undetermined

The data from Table 24 above was then used to create the graph presented in Figure 37 below.

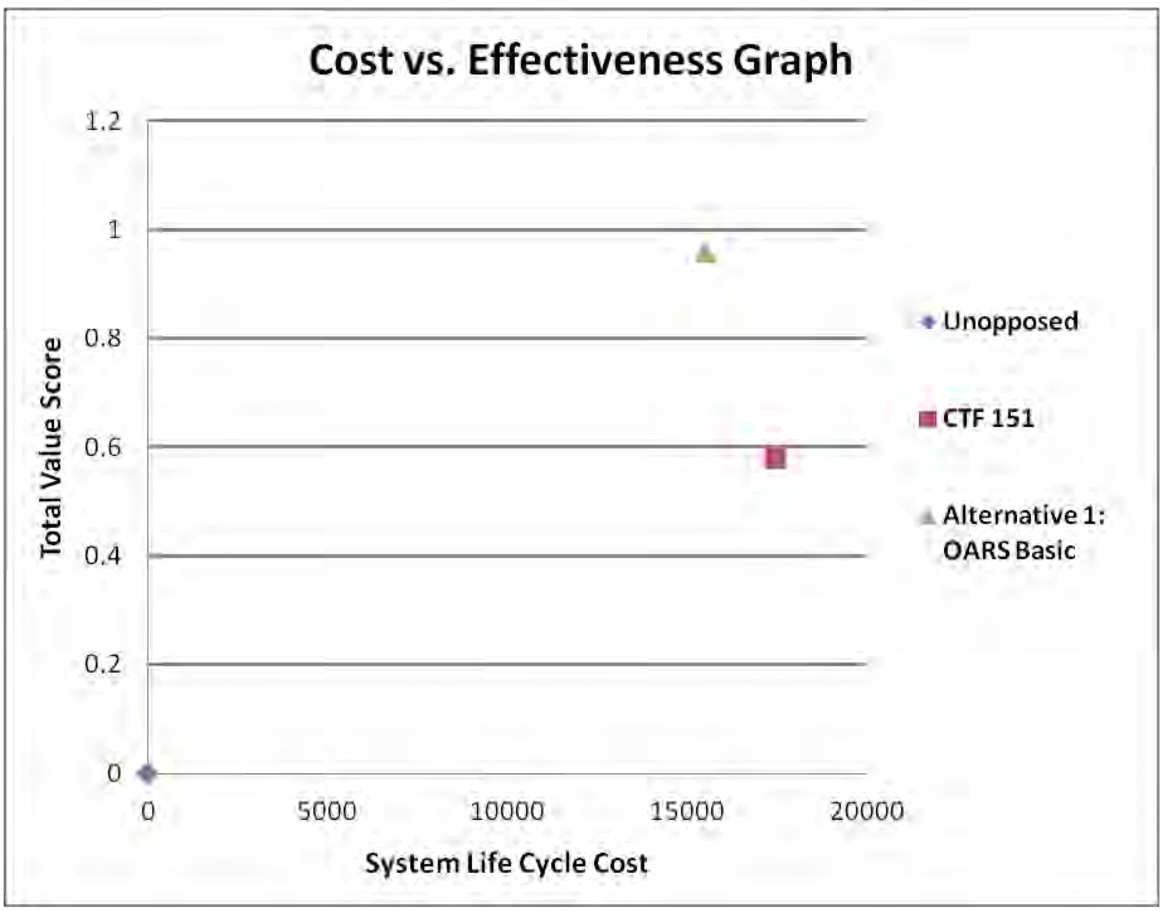


Figure 37. Cost versus Effectiveness Comparison.

Figure 37 illustrates that OARS Basic is the preferred alternative, since it dominates the CTF solution with both a lower cost and higher value score.

G. LOGISTICAL SUPPORT ANALYSIS

The document OPNAV 4000.85 (1986) addresses U.S. Naval systems logistics and breaks down logistics into three areas. These are: Acquisition Logistics, Integrated Logistics Support (ILS), and Operational Logistics.

1. Acquisition Logistics

Acquisition logistics was simplified by design. Existing commercial UAV technology was utilized. The ScanEagle is also a complete system package in itself. It is the aircraft, the launcher, the recovery system, and the ground control station. It has been fielded for years and flown numerous sorties from land as well as shipboard bases of operation. An LCS host vessel was selected because of its mission modularity and perfect suitability for UAV operations. The UAV JP-5 fuel requirement is already handled by the LCS JP-5 fueling system currently in place. The OARS support strategy uses a previously documented Performance-Based Logistics Strategy and makes it easier to focus on performance rather than the product. High failure items have already been identified for spares. Common Off the Shelf (COTS) items are being used as much as possible as well as Naval Inventory Control Point (NAVICP) on-board sparing and Navy or Commercial maintenance chains. The use of emerging technologies is discouraged.

2. Integrated Logistics

Integrated Logistics Support (ILS) for U.S. Navy Programs involves all of the support considerations necessary to ensure effective and economical support for the life cycle of ships, systems, and equipment. Because the OARS system consists of existing fielded and proven technologies and platforms, the ILS management process will be expedited. This process will involve developing support requirements consistent with the design and other requirements, integrating these considerations into the design, and providing the required support during the system or equipment life cycle at minimum cost. The in service engineering group is to also produce all hardware technical

documents as well as OARS mission operations, associated systems integration and interactions, and all maintenance requirements. These will be produced with contractor support using pre-existing commercial documentation, pre-existing LCS module documentation, as well as any new original documentation as needed.

3. Operational Logistics

Operational logistics consists of logistical and other support activities required to support the OARS system during mission operations. OARS is a user maintained system. A goal of OARS is to reduce depot level maintenance as much as possible. Initial operational and maintenance training will be conducted through the ScanEagle vendor‟s training services. Eventually the Navy will conduct its own training as system familiarity increases. Intermediate depot level maintenance will be provided when necessary. For parts support, a Consolidated Shipboard Allowance List (COSAL) will be developed to support routine maintenance as well as active mission repairs. Again, the operational logistics development will be assisted by the fact that these UAV packages already exist in the fleet.

4. Integration

As stated above, the LCS host ship concept was chosen because of its modular mission construction and its ability to carry enough UAVs needed to carry out the OARS swarm UAV missions. It can also support an SH-60 helicopter. There is plenty of room for the ground control station as well as launch and recovery platforms. Hangar space allows for efficient storage of UAVs in vertical racks. The JP-5 fuel of the ScanEagle will be supplied by the existing JP-5 fueling stations. There is space for the multiple launchers necessary to get as many UAVs airborne into the air as possible in support of a swarm mission requirement. Launchers as well as recovery hooks will be positioned along the rail of the LCS. This way, a returning aircraft does not have to cross over the deck, which creates a safer operational environment. Since the UAVs, launcher, ground control station, and recovery system comes as a package, this subsystem is already integrated. This includes the hardware, weapons, communication, and sensor payloads as well as the software and databases. All of the above will tend to reduce the overall cost

of integration. The cost of labor (number of tasks, number of workers, salary, number of man-hours for each task) will be estimated by Subject Matter Experts (SME).

5. Logistics Support and Supply Chain

The OARS system will be used to protect vessels of all nations and therefore funding for acquisition and sustainment will depend on international assistance. This process is defined in DoD 7000.14-R "International Acquisition and Cross Servicing Agreements" (2011). The sustainment program will be one of cooperation with all member states. As previously mentioned, the OARS system will be using existing DoD logistics infrastructure. An ISEA and Logistics center will be identified. It will make use of the current parts ordering system, have a Coordinated Shipboard Allowance List (COSAL) system in place for on-board sparing for deployment maintenance and repair, and follow the current parts storage policies. Depot level maintenance will be reduced as much as possible. A repair policy will be established. On-site logistics and repair support unique to the ScanEagle subsystem package will be provided by the vendor under a service level contract.

6. Operational and Maintenance Manpower

The OARS system will have a basic anti-piracy mission module consisting of the ScanEagle subsystem package, detention facilities for prisoner transport, and SH-60 helicopter operations. Typically, an LCS-2 with basic modules requires 40 core crew members which includes all enlisted and officer personnel and up to 35 mission specific personnel. The OARS system will have four ground control operators per 8 hour shift for a total of 13 onboard operators to handle a 24 hour mission, with one as a backup. There will be an additional 13 onboard launch and recovery personnel as well. The SH-60 crew needs will include 3 pilots, 3 co-pilots and 3 aviation warfare systems operators. Initially, training for each OARS system includes UAV manufacturer-provided courses. Ten weeks for each UAV operator, four weeks for each maintenance personnel, and an additional six week course which will train personnel to become instructors themselves. This will allow the Navy to conduct its own training in the future. Students will be recruited early enough to serve as each OARS system is readied for service. Student

requirements will include computer skills and physical dexterity. The cost of training is identified in the life cycle cost estimates in this report.

7. Disposal and Demilitarization

Following the guidelines in DOD 4160.21-M "Defense Material Disposition Manual" (1997), the OARS Project Manager must document all demilitarization and disposal requirements. The cost estimates for this process will be provided early on. The demilitarization plans will contain the following information for each item to be disposed of:

1. The item name.
2. How the item functions when used as intended.
3. Constituent parts of the item and its components.
4. How to disassemble and demilitarize the item and its components.
5. Safety requirements related to the item and to the demilitarization process for the item.
6. Environmental considerations and liabilities associated with the disassembly, demilitarization and disposal processes (meets environment, safety and occupational health (ESOH) requirements.

OARS subsystems, equipment, components, and parts may also be removed and replaced because of obsolescence, failures, changes, or improvements. These items, once removed, may be remanufactured, repaired, reused, refurbished, or demilitarized and disposed of at the organizational, intermediate, or depot level maintenance activity.

V. CONCLUSIONS AND RECOMENDATIONS

A. CONCLUSIONS

After all analysis was complete, the team found that the OARS Basic system provides the most detections of pirates and is the cheapest to operate. For these reasons, the OARS Basic system is the recommended anti-piracy solution.

1. Modeling and Simulation Conclusions

The modeling and simulation effort showed that OARS Basic, which had 130,379 pirate detections, was better at detecting pirates than the modeled CTF-151 solution, which had 91,171 detections. This was a 43% increase in detection. Early detection of pirate activity is crucial to its prevention. The stakeholders felt adamantly that weapons should not be implemented onto the UAVs, but instead, precise surveillance capabilities should be created. This is because pirate interdiction is not occurring in a wartime environment, which means that friendly forces cannot engage pirates with deadly force unless it is for self-defense purposes. The 43% increase in detections equaled 39,208 more detected pirates.

The modeling results did show that CTF-151 had more pirate arrests than the OARS Basic system, but this was an expected result due to the fact that the pirates were less deterred and freer to commit acts of piracy. The OARS Basic system"s use of lightweight UAVs gives it superior surveillance and reconnaissance capability, as well as a greater ability to capture incriminating evidence of pirate acts. The addition of video surveillance data will allow more pirates to be prosecuted for their acts of piracy.

2. Cost Analysis Conclusions

The total Life Cycle Cost of the two OARS alternatives and the CTF-151 solution was estimated. After the cost analysis was complete, the OARS Basic system was found to be the cheapest alternative, and had a life cycle cost that was 13% cheaper than the CTF-151 solution. The OARS Basic system was cheaper because it utilizes UAV technology to cover a greater area and therefore, requires fewer high-value ships than the

CTF-151 solution. The OARS Basic system is also comprised of the newer Littoral Combat Ships (LCS) that have a much smaller life cycle cost than today‟s naval ships.

3. Decision Metrics Conclusions

Figure 38 shows the decision metrics matrix that defines the modeling and simulation Measures of Effectiveness (MOE) as well as their global weight. Due to the crash of the modeling and simulation software database, the Naval Simulation System (NSS), all modeled scenarios and results were deleted and lost before the OARS team had a chance to model the Augmented OARS alternative. For this reason, the decision matrix only illustrates modeling MOPs for the CTF-151 solution and the OARS Basic system. The OARS Basic system received a total value score of 0.96 which was almost 40% larger than CTF-151‟s value score of 0.58.

Measure	Global Weight	Alternatives		
		Unopposed	CTF 151	OARS Basic
UAV Total Detections	0.3	0	0.7	1
UAV Total Classifications	0.3	0	0.2	1
UAV Cumulative Launches	0.1	0	0.32	1
Blue Assets Overtaken	0.25	0	0.93	1
Red Assets Overtaken	0.05	0	1	0.34
Total Value Score	**1**	**0**	**0.58**	**0.96**

Figure 38. Decision Metrics.

4. Cost Value Analysis Conclusions

Figure 39 below shows the cost versus effectiveness graph of the OARS Basic system and CTF-151. The graph shows that the OARS Basic system was both more effective and less costly than CTF-151.

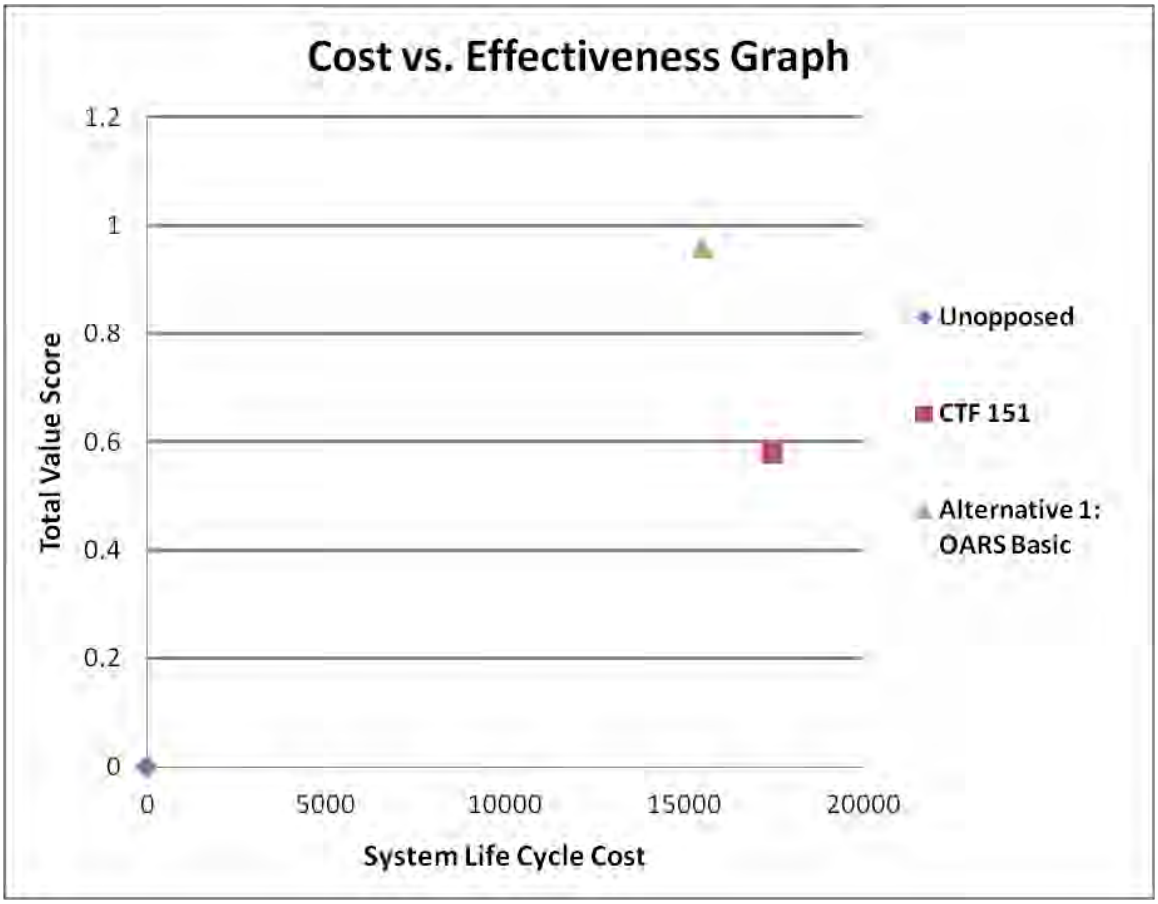


Figure 39. Cost versus Effectiveness Comparison.

5. Summary

After all analysis was complete, it was found that the OARS Basic system provides the most detections of pirates and is the cheapest to operate. For these reasons, the recommendation is the OARS Basic system.

B. RECOMMENDATIONS

1. Recommended Areas of Future Research

The analysis conducted by the OARS capstone team provided great insight into the effectiveness of UAV technology in the deterrence of piracy within the Gulf of Aden. With that being said, there are still some areas of further research that can be pursued to

provide a greater understanding of all factors involved in anti-piracy operations. The future research categories are: modeling and analysis, operational, and technical.

a. Modeling and Analysis

The modeling and analysis areas of future research identify topics that can be further researched that will provide greater insight into the OARS system"s effectiveness in anti-piracy missions.

- Due to the crash of the Naval Simulation Software (NSS), the Augmented OARS system was not modeled. The benefits of adding a Broad Area Maritime Surveillance (BAMS) UAV are still unknown, and further modeling and analysis on these benefits could provide insight into the Augmented OARS effectiveness in anti-piracy operations.
- Further research could be conducted to help better pinpoint the average force structure of CTF-151 and in turn, a better life cycle cost estimation. Due to the fluctuation of CTF-151"s force structure and its unique use of ships from many countries, estimating its" life cycle cost was difficult.

b. Operational Areas

The operational areas of future research focus on the operational areas where the OARS system may be utilized worldwide. These potential research topics will provide more insight into the OARS system"s ability to be used to fight piracy worldwide.

- Additional operational areas of anti-piracy operations need to be analyzed. The OARS team focused on deterring piracy within the Gulf of Aden, which provides a unique, narrow corridor of operation. However, Somali piracy has been expanding into the Indian Ocean and therefore, use of the OARS systems in a more open ocean environment should be examined.

c. Technical Areas

The technical areas of future research mostly define subsystems of the OARS systems that require more research to define their validity in anti-piracy missions.

- Evaluation of the MQ-8B Fire Scout Vertical Takeoff Unmanned Aerial Vehicle (VTUAV) as a replacement to the SH-60 Helicopter for anti-piracy missions. The OARS team ruled out the use of the Fire Scout due to the fact that it did not aid in the detention and capture of pirates,

however, the Fire Scout is significantly less costly to operate and deserves further research into its use in anti-piracy operations.

- Further research needs to be conducted on the host vessel‟s ability to intercept and monitor the pirates‟ handheld satellite communications and Global Positioning Systems (GPS). The pirate‟s use of technology was limited, but the ability of the commander to monitor this information would be a crucial asset to anti-piracy operations.

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APPENDIX A STAKEHOLDER COMMENTS

Captain Brown

- CO of CG-64 Captured 38 suspected pirates and one mothership
- UAVs should not have lethal force
- Host vessel should maintain a chain of evidence (i.e. video record of suspected pirates dumping their weapons overboard) for the detention and prosecution of pirates.

LT Cook

- UAVs should not have lethal force
- Evidence collection necessary and demanding
- Identification of pirates was very important and made the boarding party much safer

Captain Place (ret USN)

- UAVs need high grade JP fuel
- IRIDIUM use for Command and Control
- AIS Automatic Identification System
- LCS radars are good for tracking
- Deploy EO IR Systems for ID
- ScanEagle 80 nm range EO IR capability
- Fire Scout is modular and helpful
- BAMS goes to $120M
- ScanEagle with 6 birds is $5M by INSITU

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APPENDIX B FUNCTIONAL FLOW BLOCK DIAGRAM (FFBD)

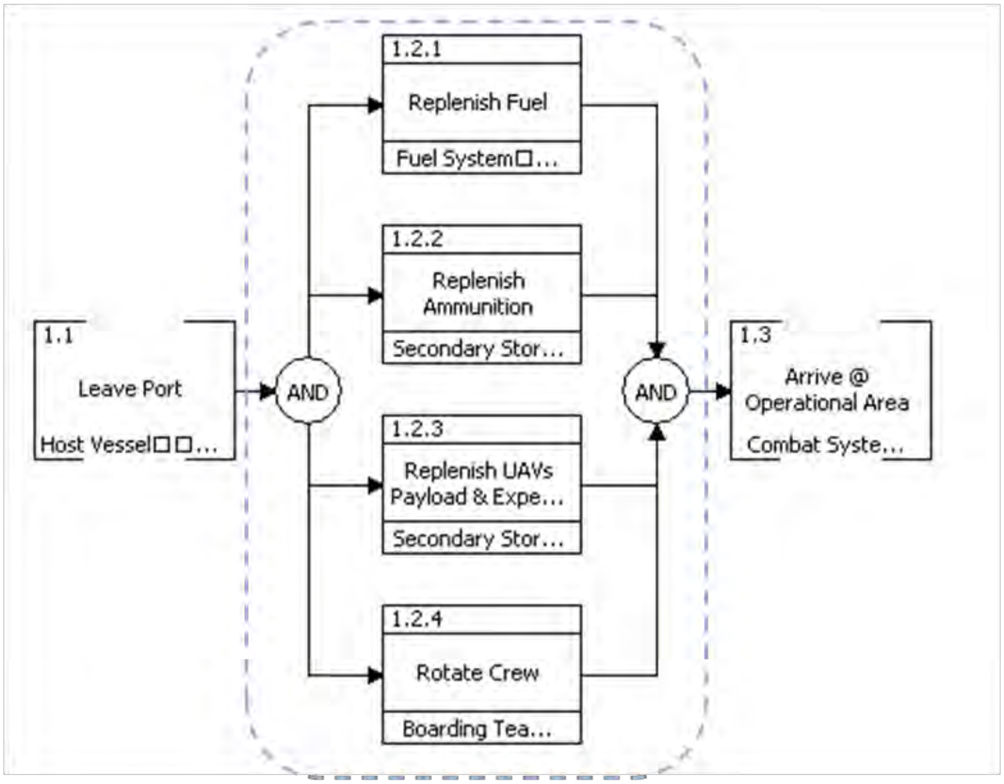

Figure 40. FFBD 1.2, „Underway Replenishment"

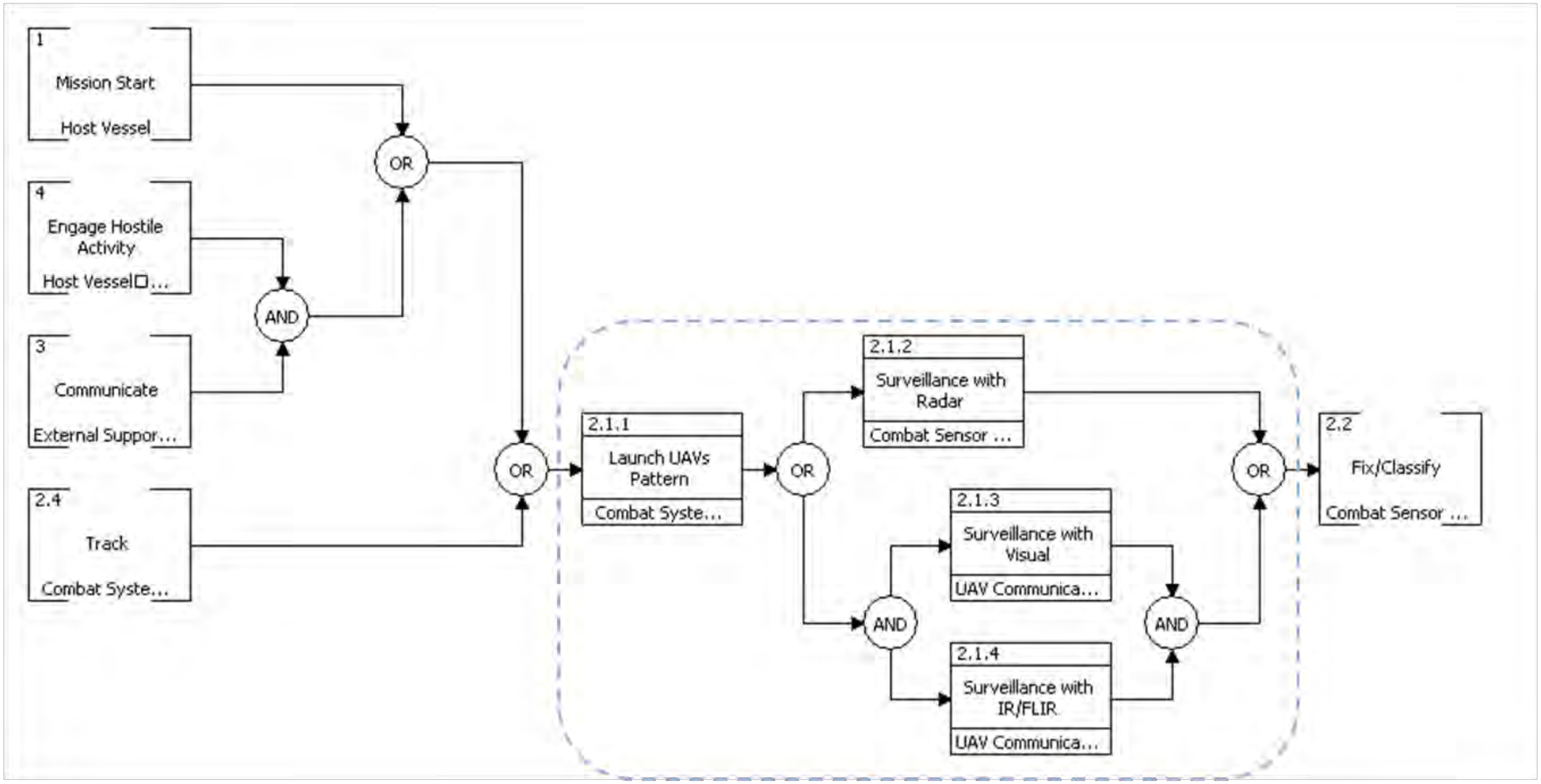

Figure 41. FFBD 2.1, „Detect"

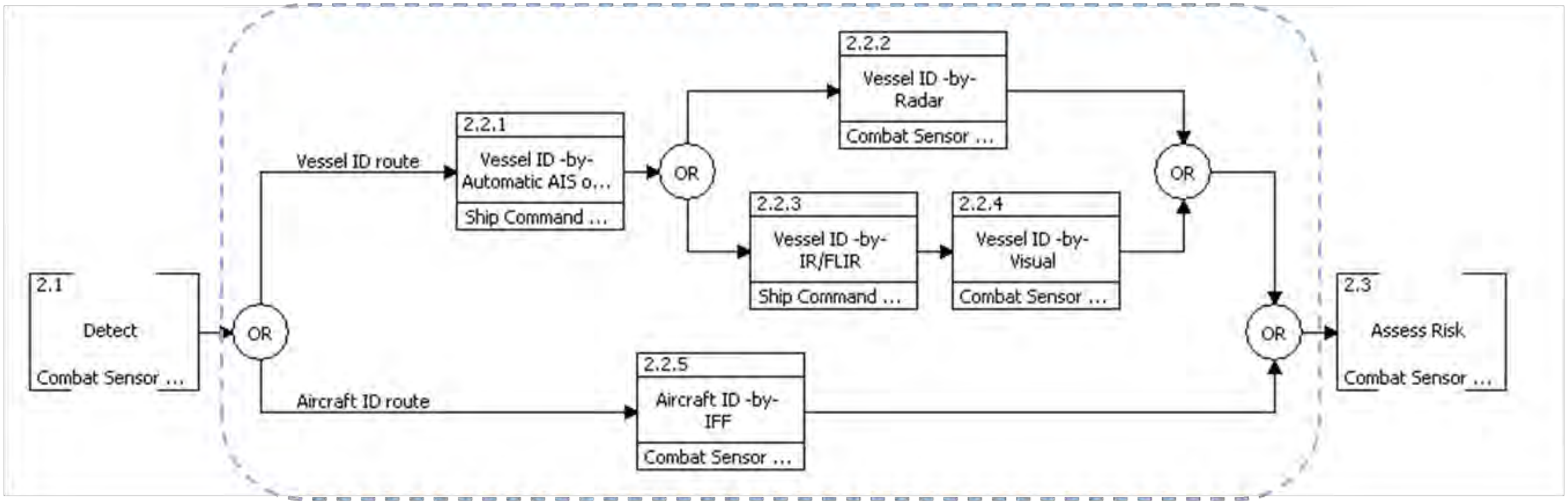

Figure 42. FFBD 2.1, „Fix/Classify"

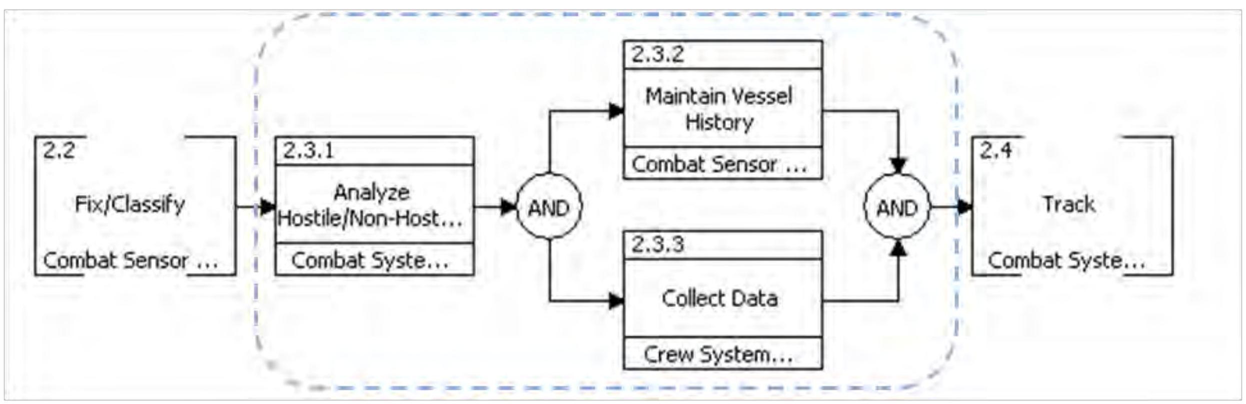

Figure 43. FFBD 2.3, „Assess Risk"

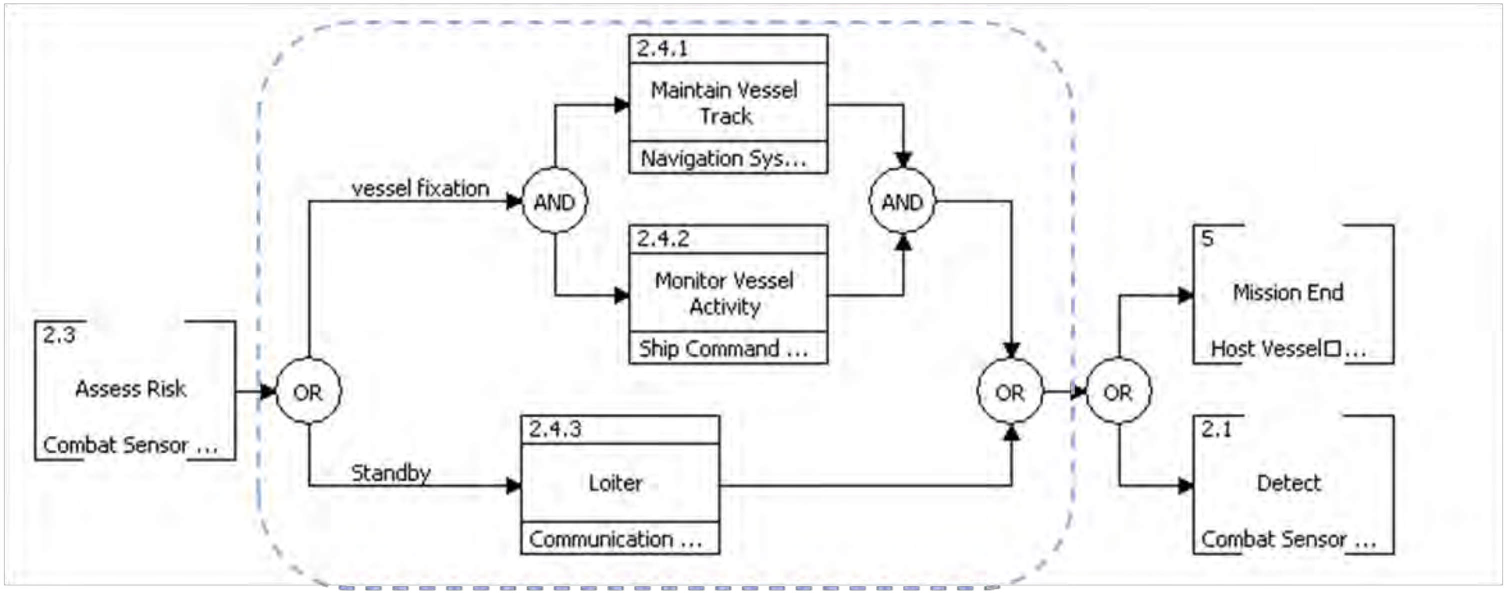

Figure 44. FFBD 2.4, „Track"

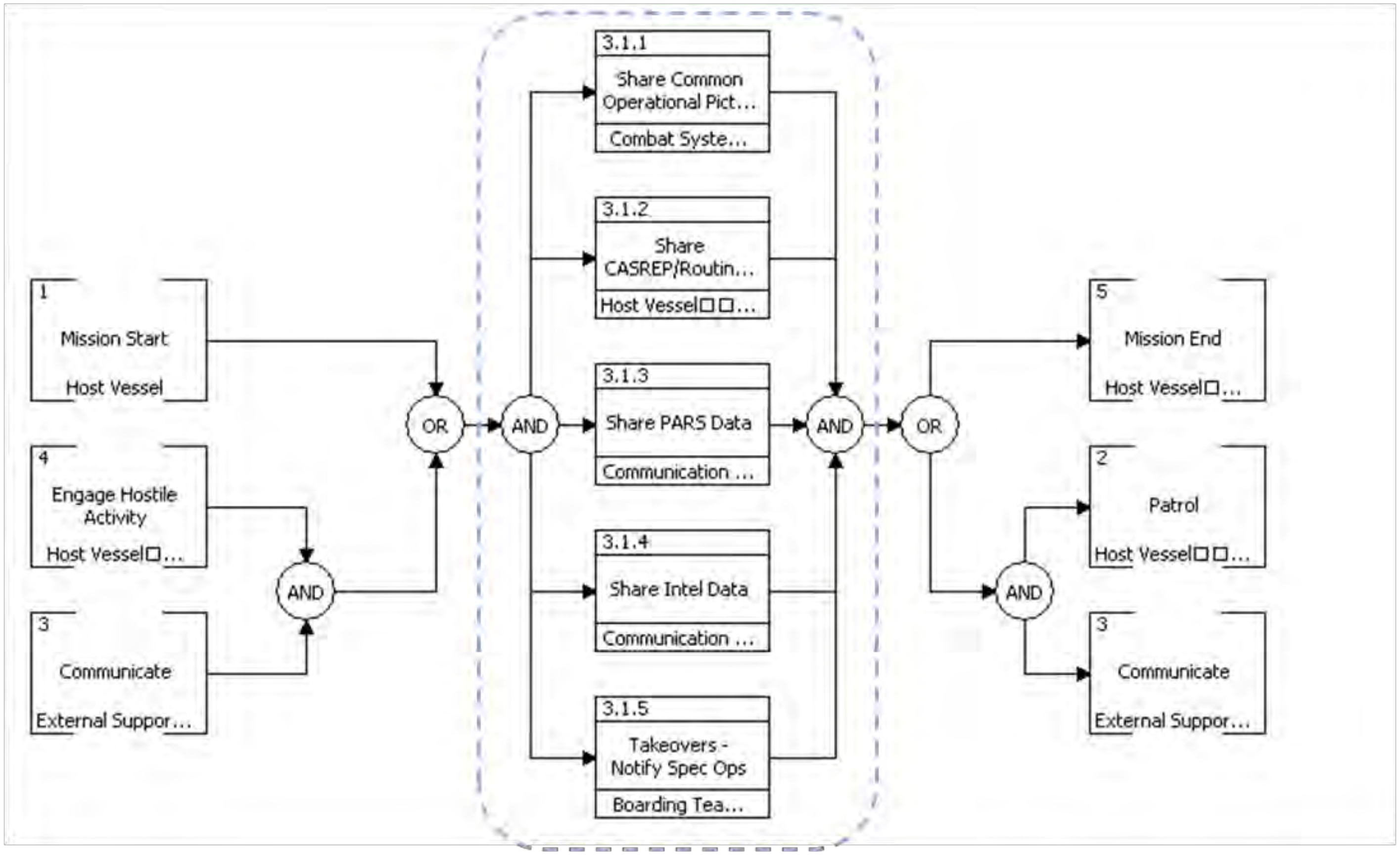

Figure 45. FFBD 3.1, „Communicate Internally – Fleet Command"

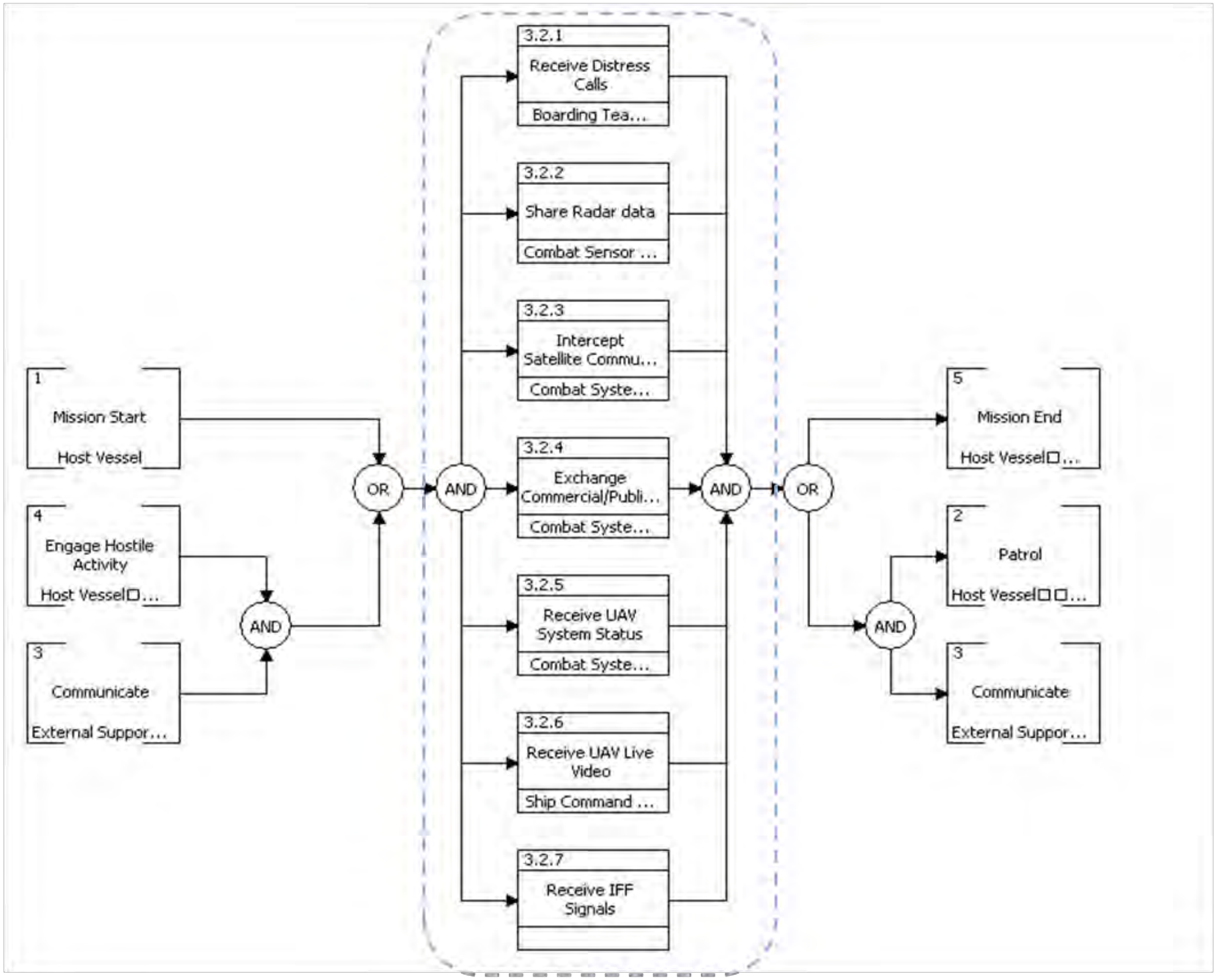

Figure 46. FFBD 3.2, „Communicate Internally – OARS Fleet Command & Control"

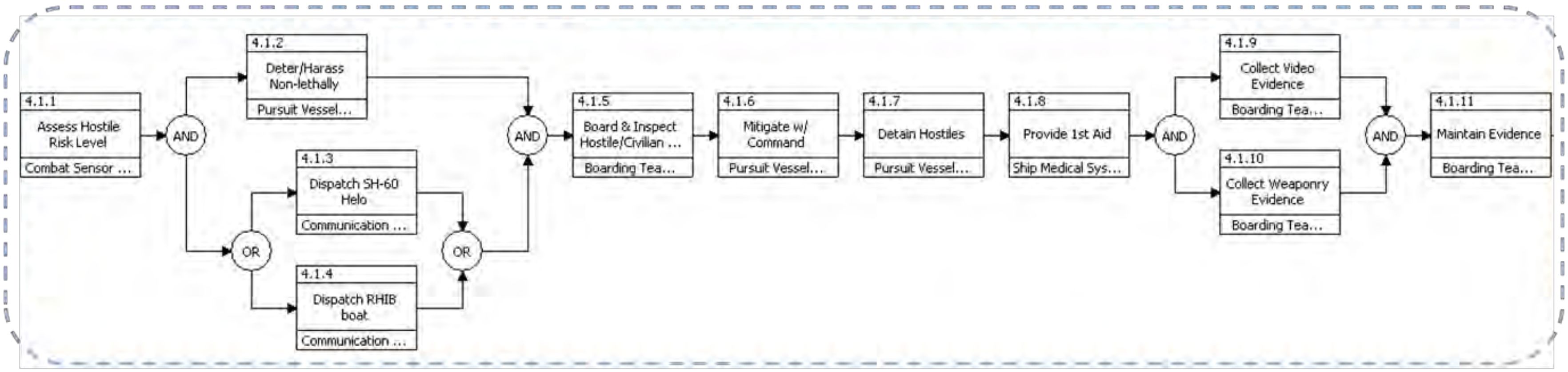

Figure 47. FFBD 4.1 „Intercept"

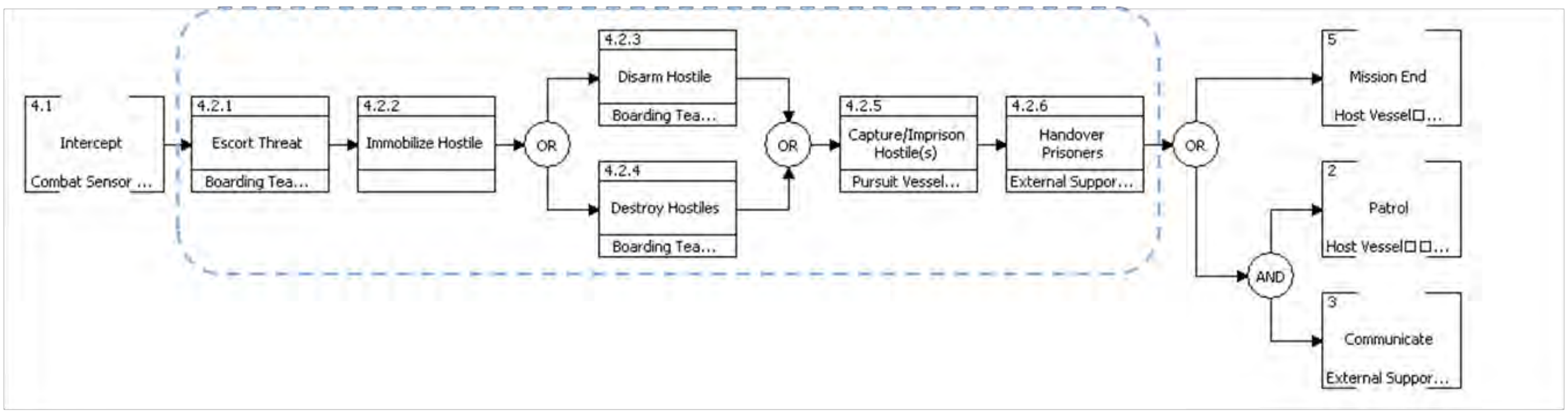

Figure 48. FFBD 4.2, „Neutralize"

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APPENDIX C MODELING SCENARIO NUMBERS

# of Ships				**CTF 151**	**All CTF's**
Merchant Ships per 1.1 million mi^2				**500/Day**	
US Naval Vessels				**3**	**17**
Coalition Vessels				**10**	
Pirate Skiffs				**20/Day**	
Pirate Motherships				**3/Day**	
Pirate Origin/Base				**Eyl**	———
Coordinates					
Lat				**7N58'39.5"**	
Long				**49E49'22.8"**	
Pirate Assumptions/Calculated Values					
Skiff Speed (max)				**40 knots**	
Skiff Endurance (2 Fuel Cans)				**15 Gallons**	
Skiff Range (from Mothership)				**23 mi**	
Mothership Speed (max)				**10/ 9 ave knots**	
Mothership Endurance				**4950 Gallons**	
Mothership Range (max)				**4000 mi**	
Pirate Probability Assumptions					
Distance	***Probability of Overtaking Vessel***				
5 miles	**0.25**				
4 miles	**0.35**				
3 miles	**0.45**				
2 miles	**0.6**				
1 mile	**0.75**				
.5 mile	**0.8**				
.25 mile	**0.9**				
.1 mile	**0.95**				

Under CTF	Alternative 1 - CTF 151		
	Naval Vessels	***Class of vessel***	***3***
y	DDG 51 Class	Arliegh Burke	1 (rotating
y	FFG Class	Perry	2
y	LPD 17 Class	San Antonio	1 (rotating
	Coalition Vessels		***10***
n	Chinese Frigate	Jianwei	2
y	Korean Frigate	ULSAN	1
y	Turkey Frigate + SH60B Sea Hawk	Barbaros	3
y	Signapore Destroyer+ SH60U SeaHawk	Formidable/La Fayette Corvette class frigate	2
y	Canadian Destoryer + SH3D Sea King UAV	HMCS Regina/Algonquin Frigate/Iroquois/Tribal/Halifax Frigate	1
y	French Frigate + Z9C Dauphin UAV	Floreal	1
	Boarding RHIB Boats(none in model)		***28***
y	DDG 51 Class		2
y	FFG Class		4
y	LPD 17		2
n	Chinese Frigate		4
y	Korean Frigate		2
y	Turkey Frigate		6
y	Signapore Destroyer		4
y	Canadian Destoryer		2
y	French Frigate		2

Alternative 2 - LCS Mothership	
Naval Vessels	*3*
LCS Class	1
DDG 51 Class	1
LPD 17 Class	1
Coalition Vessels	*10*
Chinese Frigate	2
Korean Frigate	1
Turkey Frigate	3
Signapore Destroyer	2
Canadian Destoryer	1
French Frigate	1
Boarding RHIB Boats	*18*
DDG 51 Class	2
LCS Class	2
LPD 17	2
Chinese Frigate	2
Korean Frigate	2
Turkey Frigate	2
Signapore Destroyer	2
Canadian Destoryer	2
French Frigate	2
UAV - Option 1	*16*
Scan Eagle (LCS)	9
Scan Eagle (DDG)	3
Scan Eagle (LPD)	4
UAV - Option 2	*9*
UAV 2 (LCS)	4
UAV 2 (DDG)	2
UAV 2 (LPD)	3
UAV - Option 3	*9*
UAV 3 (LCS)	4
UAV 3 (DDG)	2
UAV 3 (LPD)	3
Land Bases	*1*
5th Fleet HQ - Bahrain	1
Refueling Bases	*2*
Dubai	1
Quatar	1

Alternative 3 - Air Mothership	
Naval Airships	*1*
MDL-100X1 Dynalifter	1
Naval Vessels	*2*
DDG 51 Class	1
LPD 17 Class	1
Coalition Vessels	*10*
Chinese Frigate	2
Korean Frigate	1
Turkey Frigate	3
Signapore Destroyer	2
Canadian Destoryer	1
French Frigate	1
Boarding RHIB Boats	*16*
DDG 51 Class	2
LPD 17	2
Chinese Frigate	2
Korean Frigate	2
Turkey Frigate	2
Signapore Destroyer	2
Canadian Destoryer	2
French Frigate	2
UAV - Option 1	*9*
Scan Eagle (Dynalifter	2
Scan Eagle (DDG)	3
Scan Eagle (LPD)	4
UAV - Option 2	*7*
UAV 2 (Dynalifter)	2
UAV 2 (DDG)	2
UAV 2 (LPD)	3
UAV - Option 3	*7*
UAV 3 (Dynalifter)	2
UAV 3 (DDG)	2
UAV 3 (LPD)	3
Land Bases	*1*
5th Fleet HQ - Bahrain	1
Refueling Bases	*2*
Dubai	1
Quatar	1

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APPENDIX D RISK MANAGEMENT

A. RISK MANAGEMENT STRATEGY

Risk can be defined as "…the net negative impact of the exercise of vulnerability, considering both the probability and the impact of occurrence" (NIST, 1). Risk management is a continuous process that is accomplished throughout the life cycle of a system. It is a process that encompasses risk identification, analysis, assessment, mitigation planning, mitigation implementation, monitoring, and tracking. Early identification of the OARS project risks allowed for early implementation of mitigation strategies and therefore improved the likelihood of the project achieving its stated objectives. Risks were identified during project analysis, established and reviewed with primary stakeholders, and continuously monitored and managed throughout the OARS project‟s lifecycle. Risks were managed by order of criticality and the data obtained was documented. The risk management IPT created a risk management strategy that illustrated the process in which the OARS team used to mitigate risks.

A risk mitigation strategy was developed to assist in the mitigation process in order to determine whether or not an improvement was acceptable. The strategy defined how risks were managed throughout the lifecycle of the project. For this strategy, there were three stages. These stages were:

1) Risk Assessment.

2) Risk Control.

3) Risk Review.

Proper processes were instilled in the OARS‟ risk management effort to ensure that sufficient communication of risk information was provided to all involved. Model 1 below displays the OARS Team‟s Risk Management Strategy along with the three stages involved. The OARS risk management process was initiated and used to assess, mitigate and review the risks. If in the control stage, the risk is unacceptable, it returned to the assessment stage for reevaluation and/or removal. If the risk is accepted, it moved forward through documentation and review. During the review, if a risk was discovered that was not previously anticipated, the risk was passed backwards to the Risk Control

stage and if necessary, back to the Risk Assessment stage. Each stage of the risk management process will be discussed, beginning with Risk Assessment.

Risks were managed by order of criticality and the data obtained was documented. There were three areas of importance in the OARS team"s risks. The areas of importance were as follows: Technical Risk, Model Risks, and Project Risk. Once the risks were established, a Risk Prioritization Matrix was then developed. Below is a breakdown of the biggest risks that were identified during the project, as well as their mitigation strategies.

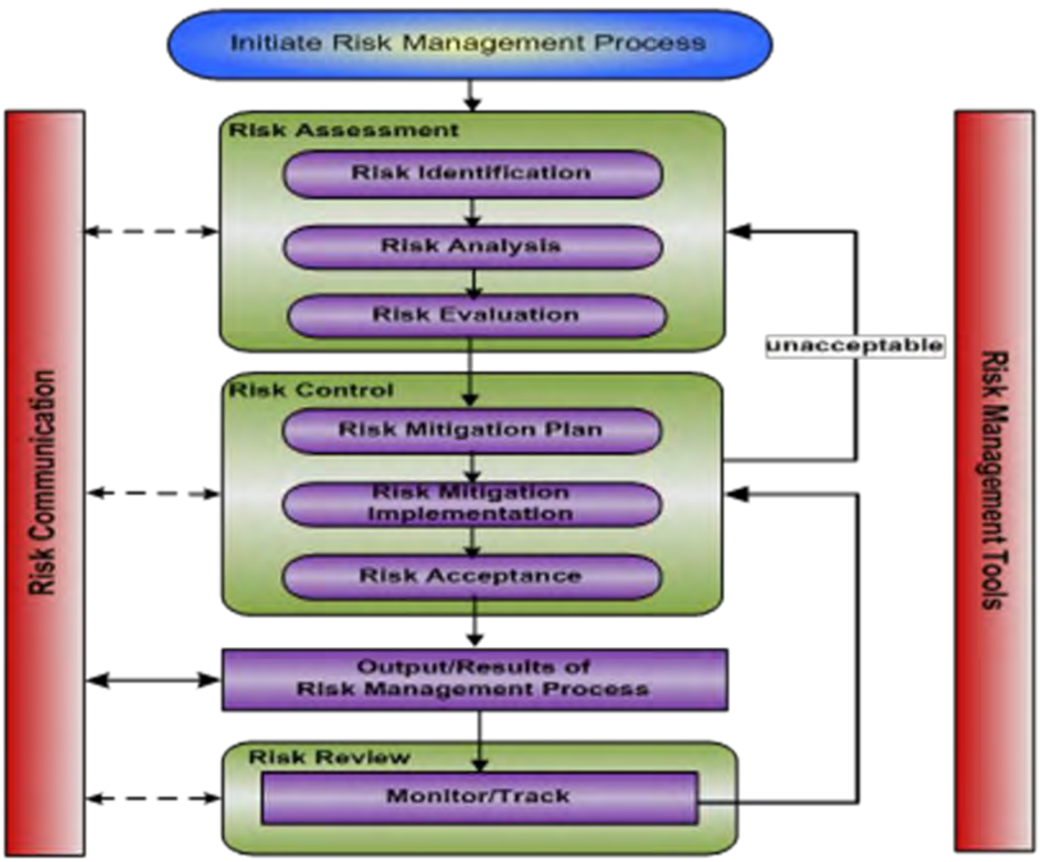


Figure 49. Risk Management Process.

1. Stage 1 Risk Assessment

Risk assessment is the identification, analysis, and evaluation of the levels of risks involved in a situation as shown in Model 2 below. It is the first stage of the risk

management process that will determine whether or not there is an acceptable level of risk for the OARS system.

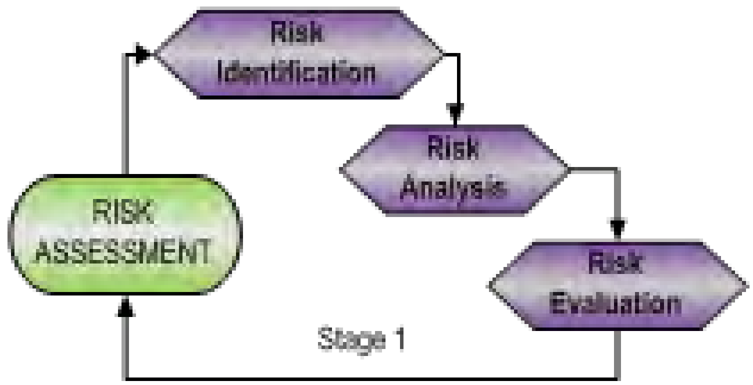


Figure 50. Stage 1, Risk Assessment.

a. Risk Identification

Risk identification is the activity that examines each element of the project to identify associated cause, begin documentation, and set the stage for the successful OARS risk management process. To identify any risks of the OARS project, the "what can go wrong" questions were asked. To answer the questions, "IF – THEN" statements were formed. A condition-to-consequence risk statement was generated. For example, IF Coalition forces do not acquire pirate identification in time, THEN the probability of pirate boarding increases. A table containing the top eight risks was developed using this method and is shown below. The risk number values were taken from the Risk Reporting Matrix (RRM), located in Section 1.1.1.2. Once the risks were identified, the next step in the process was to complete a risk analysis of the system.

Table 25. Identified Risks with Partial Mitigation.

No.	RISK	Impact	Likelihood	Risk Type	Manage/Mitigate
1	IF OARS cannot complete the M&S activity, THEN system will lack data for consideration of alternatives	C	90%	Model	Overcome technical NSS difficulties with SME Metron
2	IF Coalition forces do not acquire pirate identification in time, THEN the probability of pirate boarding increases	C	30%	Mission	Have capability to sense targets of interest
3	IF Differential GPS mounted on UAV or Skyhook is damaged while in operation, THEN recovery of UAV would be difficult	S	20%	Technical	Use alternative method to recover UAV (Net)
4	IFOARS system to system integration has incompatibility problems THEN a failure could occur causing loss of craft.	Mo	40%	Technical	Select a proven software/hardware package
5	IF Coalition have proprietary issues with technology, THEN the objectives for the effort will not be fulfilled	Mi	5%	Mission	Build equipment using international standards (ISO) for quality and manufacturing
6	IF Coalition lacks ability to adapt to change in pirate tactics and weapons, THEN increased loss of assets will occur.	C	30%	Operational	Acquire FOUO Intel on pirate tactics and weapon acquisition to monitor pirate activity
7	IF Multiple attacks to several commercial ships occur at the same time, THEN there could be a loss of situation awareness and safety to Civilian vessels is compromised	C	50%	Technical	Review technical specifications that has contingency for swarm effect
8	IF new capabilities and requirements are added to the OARS system, THEN more testing will be required, causing possible delay in project completion	S	20%	Technical Cost	Involve stakeholders in future planning for Intel. Delay code freeze until latest possible time
9	IF OARS cannot be fully supported by necessary manpower due to injury, THEN the ability to operate OARS efficiency will be an issue	S	10%	Personnel	Use of IMPRINT and involvement of HSI early in the development process. IMPRINT-N for Navy
10	IF there is limited capability for scenarios in M&S, THEN the ability to see full measure of OARS capability will be limited as well.	Mo	30%	Model	Accept risk
11	IF OARS lack stakeholder requirements, THEN the actual recommended solution may not correctly address the need	Mi	10%	Project	Retrieve sufficient stakeholder input in the requirement solicitation process
12	IF deployment schedule is to stringent, THEN OARS system may not be mission capable	Mo	20%	Project	Reorient schedule to follow incremental deployment
13	IF budget cannot allocate funding to OARS system by procurement date, THEN system cannot be implemented	S	50%	Project	Acquire proper all procurement and operations support

Mi = Minor   Mo = Moderate   S = Serious   C = Critical

b. Risk Analysis

Risk analysis involves identifying the most probable risks to the project and analyzing the related vulnerabilities to these risks. The intent of risk analysis was to answer the question "How big is the risk?" This is accomplished by:

- Considering the likelihood of the risk occurrence,
- Identifying the possible consequences/impact for this project in terms of schedule, and

- Identifying the risk level using the Risk Reporting Matrix shown in Figure 51 below.

A Quantitative risk assessment requires calculations of two components of risk: the consequence/impact of the potential loss, and the probability that the loss will occur. The OARS team defined the criteria for likelihood and consequence or impact for evaluating the project‟s risk. The use of the Risk Reporting Matrix below displayed the level of the risks identified within the project. The level of risk was then documented with a consequence/impact ranging from negligible to critical. In Figure 1, the level of likelihood of each risk was established using specified criteria. The level of likelihood for the OARS project ranges from “remote” to “near certainty.” For example, if the risk has an estimated 50 percent probability of occurring, the corresponding likelihood is “likely.”

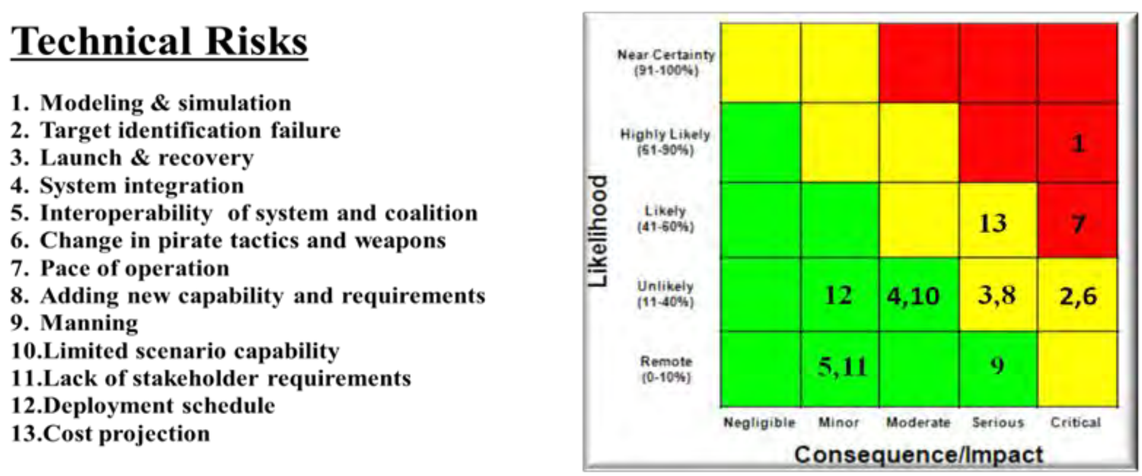


Figure 51. OARS Risk Matrix.

To analyze the risks even further, the OARS team also used fault trees to illustrate the undesired state of the system. The use of fault trees assisted with the determination of system functional failure probability.

c. *Fault tree analysis (FTA)*

The fault tree was one of the methodologies used for each of the OARS risks. It helped to determine whether or not the risk was acceptable. This tool assumes failure of the functionality of a product or process (Kirupakar 2011). The results were represented pictorially in the form of a tree of fault modes. This was used to investigate complaints or deviations, and allowed the team to fully understand their root cause and ensure that intended improvement would resolve the issues and not cause any other problems (Kirupakar 2011). A good example of this tool is provided below in figure 3.

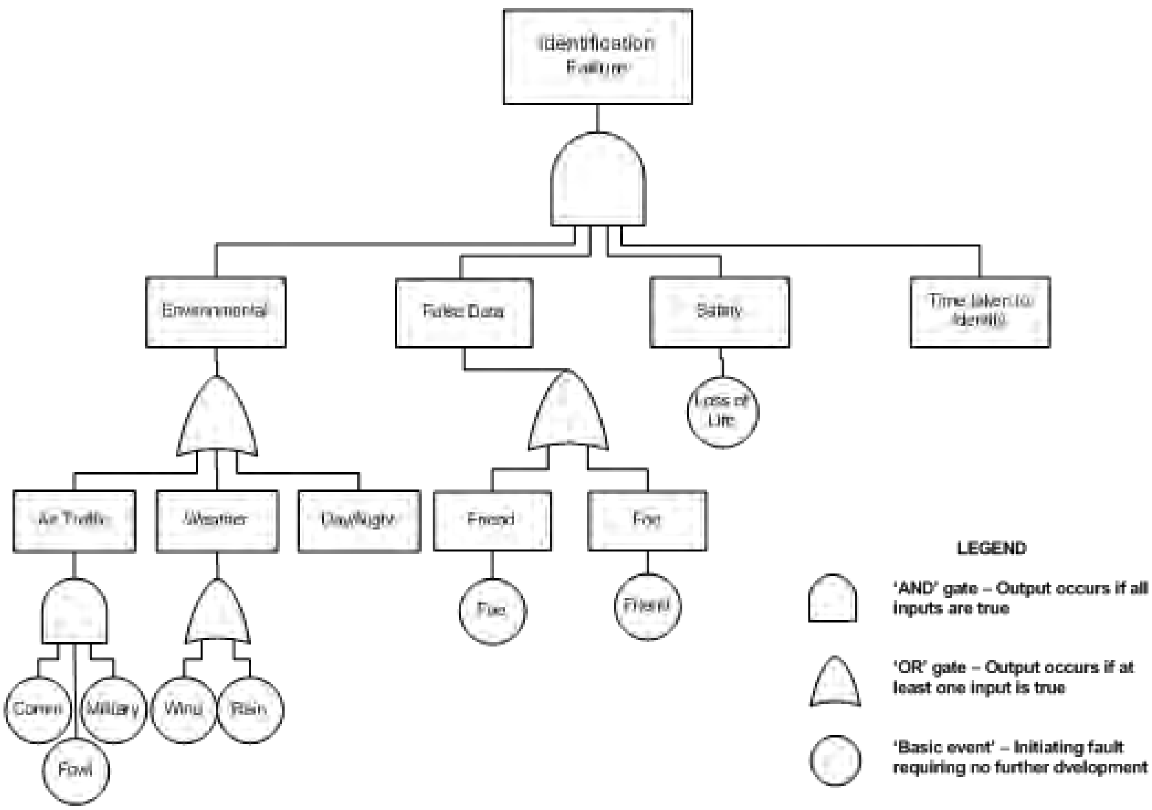


Figure 52. Fault Tree Analysis of Identification Failure Risk.

Figure 3 shows a representation of a fault tree for the first technical risk of the OARS system. This tree introduces complex units known as "gates," which serve to allow or hinder the passage of fault logic up the tree. The gates show the relationships of events that are needed "higher" events to occur (Vesely 1981). In this case, "Identification failure" is the higher event, which is the output of the „and" gate. The

lower events are the inputs to the „and" gate. The „AND" gate is used when the output occurs if all the inputs are true. The „OR" gate is used when the output occurs if at least one of the inputs are true. The „basic event" symbol is used when initiating a fault requiring no further development.

d. Risk Evaluation

Risk evaluation is the process of analyzing potential losses from a given risk using a combination of known information about the situation, knowledge about the underlying process, and judgment about the information that is not known or well understood. The OARS team was assigned to each identified risk, with priority given to the most critical risks first. The OARS team"s risk evaluation involved assessing existing controls and their adequacy relative to the potential threats.

2. Stage 2 Risk Control

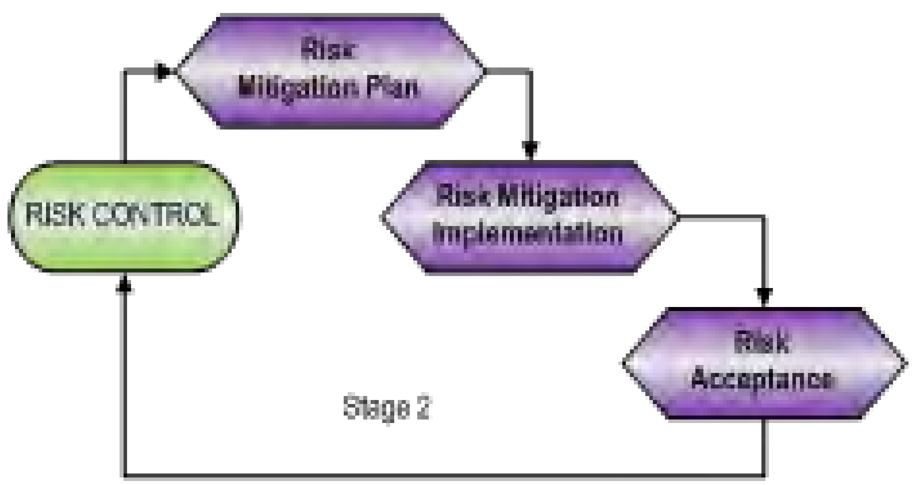


Figure 53. Stage 2 Risk Control.

a. Risk Mitigation Plan

The objective of the OARS risk mitigation efforts was to lower the probability of the risk event occurrence, and to explore risk response strategies for the high risk items identified in the qualitative and quantitative risk analysis. The process identified and

assigned OARS IPTs to take responsibility for each risk response. It ensured that each risk requiring a response had an owner. The intent of risk mitigation planning was to answer the following question: "What is the program approach for addressing this potential unfavorable consequence?" One or more of the following mitigation options may have applied:

1. Avoid risk by eliminating the consequence/impact,
2. Control the likelihood and consequence/impact,
3. Transfer the risk,
4. Accept the level of risk and continuing on the current project plan.

Table 26 represents some of the tools and techniques that the OARS team used to assist in reducing the likelihood of the risks occurring.

Table 26. Risk Tools. (From Engineering Risk Benefit Analysis. DoD Risk Management V03-25-201).

PERSONNEL	PROCESS	TECHNOLOGY
TRAINING	DEFINE REQUIREMENTS	USE PROVEN TECHNOLOGY
HIRING/PROMOTION	DESIGN REVIEWS	MOCK-UPS & PROTOTYPING
COMMUNICATION	RIGOR	TECHNOLOGY MATURATION
LEADERSHIP	TEST PROGRAM	REDUNDANT DESIGN
KNOWLEDGE SHARING	TRADE STUDIES	ROBUST DESIGN
	MODELING & SIMULATION	OPEN SYSTEMS

b. Risk Mitigation Implementation

After the risks had been analyzed and documented according to their levels of priority in the mitigation plan, the development and integration of the corresponding risk

mitigation strategies followed and were referenced against the previously prepared risk management plan.

c. Risk Acceptance

The concept of risk acceptance asked the question, "How safe is safe enough?" The OARS team collaborated with its stakeholders in determining the acceptable level with which some risks within the project would be allowed.

2. Stage 3 Risk Review

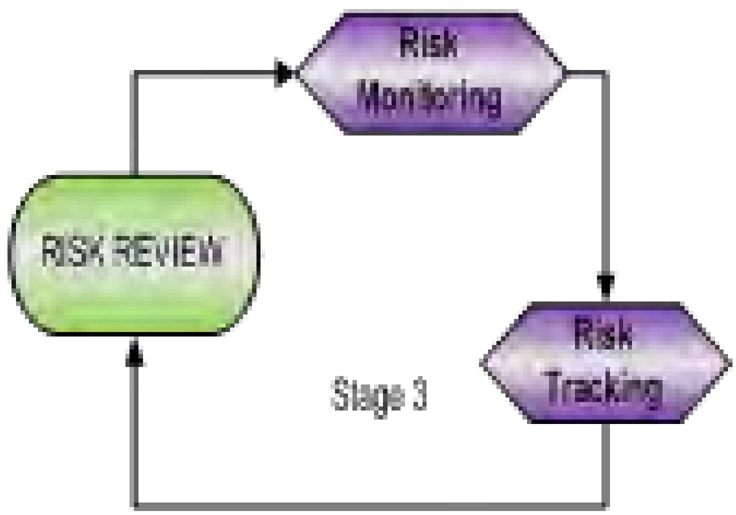


Figure 54. Stage 3 Risk Review.

a. Risk Monitoring and Tracking

Risk monitoring and tracking "is the process for tracking identified risks, monitoring residual risks, identifying new risks, executing risk response plans, and evaluating their effectiveness throughout the project life cycle" (Project Management Institute 2008, 237).

The OARS risks were regularly monitored and tracked through the lifecycle of the project. The OARS team monitored and tracked the risks in intervals of weekly meetings. The meetings addressed the implementation of risk handling actions and their impact to the project. The OARS team monitored risk mitigation plans and their

progress, reviewed and updated risk status, and communicated the risks to all affected stakeholders. The status of each risk was displayed on the Risk Reporting Matrix discussed earlier in this document. The OARS team communicated any changes in the risks and mitigation plan with the appropriate personnel.

B. OARS RISK ANALYSIS

Risks were managed by order of criticality and the data obtained was documented. There were three areas of importance in the OARS team‟s risks. The risks were as follows: 1. Technical Risk, 2. Model Risks, and 3. Project Risk. Once the risks were established, then a Risk Prioritization Matrix was developed.

1. Technical Risks

Risk #7: Pace of Operation. The inability of OARS to handle simultaneous attacks would cause loss of situational awareness. Mitigation Strategy: Review technical specifications which have a contingency plan for swarm effect and implement when necessary.

Risk #6: Change in Pirate Tactics (OARS inability to adapt to the change in opponent tactics resulting in mission failure). Mitigation Strategy: Acquire "For Official Use Only" (FOUO) intelligence on pirate tactics and weapon acquisitions to monitor pirate activity in real time.

Risk #2: Target Identification Failures. This had a large potential for OARS to be unable to detect/identify pirates in a timely manner causing mission failure. Mitigation Strategy: Utilize proven capability to sense targets of interest with backup contingencies.

2. Model Risks

Risk #1: The M&S team was new to the NSS modeling & simulation program and had very little experience, requiring oversight from knowledgeable associates. Hence, actual model results may not be accurate, resulting in an improperly recommended solution. Mitigation Strategy: The team attempted to mitigate this problem by proactively meeting 2-5 times a week to facilitate rapid learning and model construction.

Risk #10: NSS Software Limitations. The OARS NSS model was very limited in contrast to what scenarios the M&S team wanted to simulate. The objective was to model the entire Indian Ocean, but only the Gulf of Aden was modeled because of time restrictions and program capabilities. Mitigation Strategy: Accept the Risk.

3. Project Risks

Risk #8: Requirements/Capability Change. This could change the scope, requirements, and capabilities incurring delays and increased development cost. Mitigation Strategy: Involve stakeholders in future planning for intelligence and delay code freeze until latest possible time

Risk #11: Lack of stakeholder requirements. The OARS project had few participating stakeholders. Stakeholder feedback was very limited. Hence, the recommended solution may not correctly address the actual needs and requirements of the stakeholders. Mitigation Strategy: To reduce this risk, the Stakeholder IPT made many attempts to retrieve stakeholder feedback in the requirements solicitation process. It is recommended that any future development of this proposal re-solicit stakeholders for further feedback.

Risk #12: Deployment schedule. The OARS project has a projected deployment date of 2020. Because of this tight deployment schedule, OARS may not be mission capable by this date, thus failing to meet the needs of the stakeholders. Mitigation Strategy: Re-orient the deployment schedule to follow an incremental deployment schedule. Hence, incorporate additional UAVS and increase capabilities as successful fielding occurs.

Risk #13: Cost projection. Due to a decrease in weapon system budget allocation, obtaining the expected costs for the OARS system may be at risk through 2016, which is the projected congressional authorization. Mitigation Strategy: Acquire proper Ally procurement and operations support.

4. Risk Prioritization Matrix

Now that the three categories of risks have been established, a prioritization matrix of those categories was developed in order to show the overall status of the risks of the OARS system.

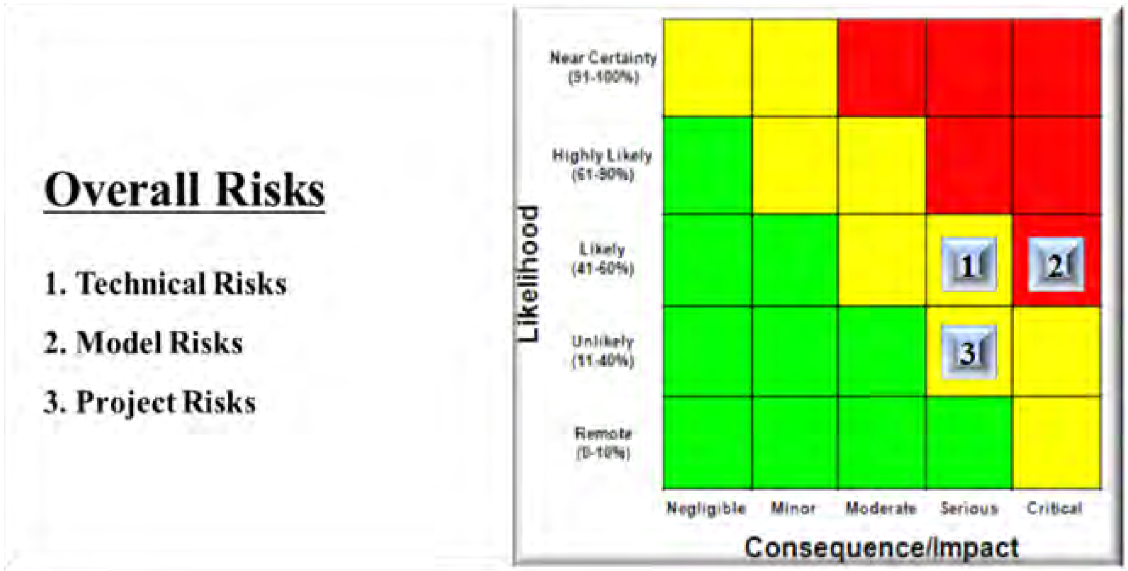


Figure 55. OARS Risk Matrix.

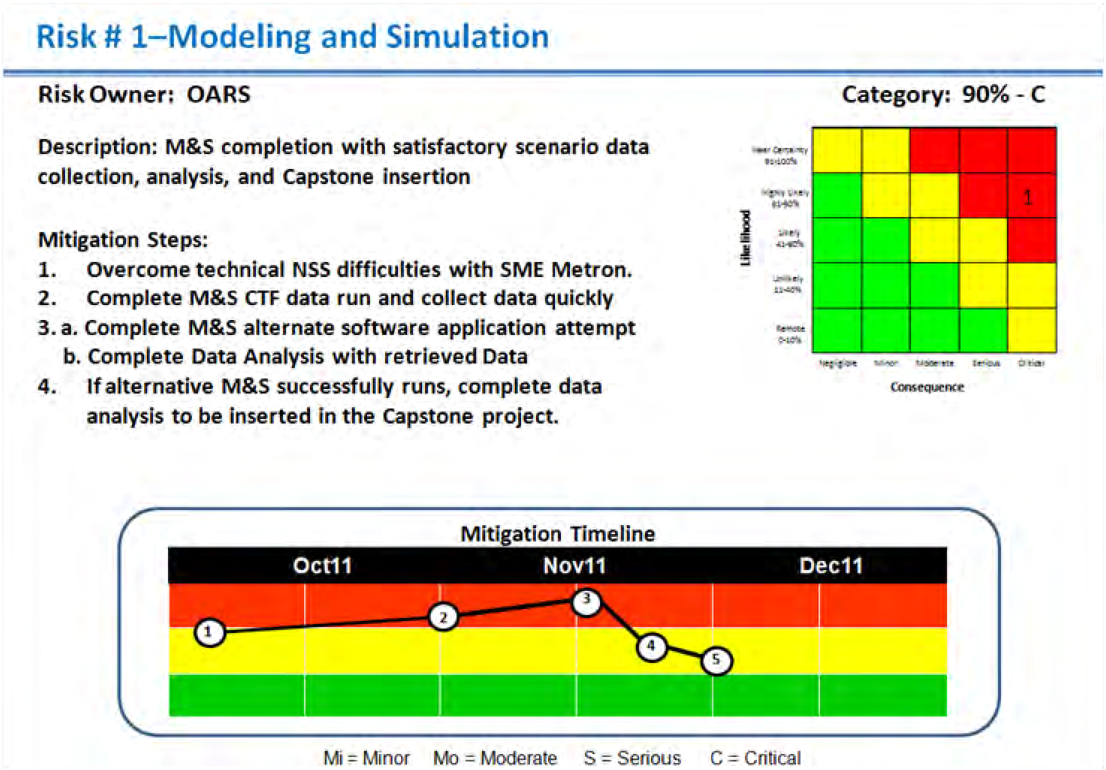


Figure 56. Risk #1: Modeling and Simulation.

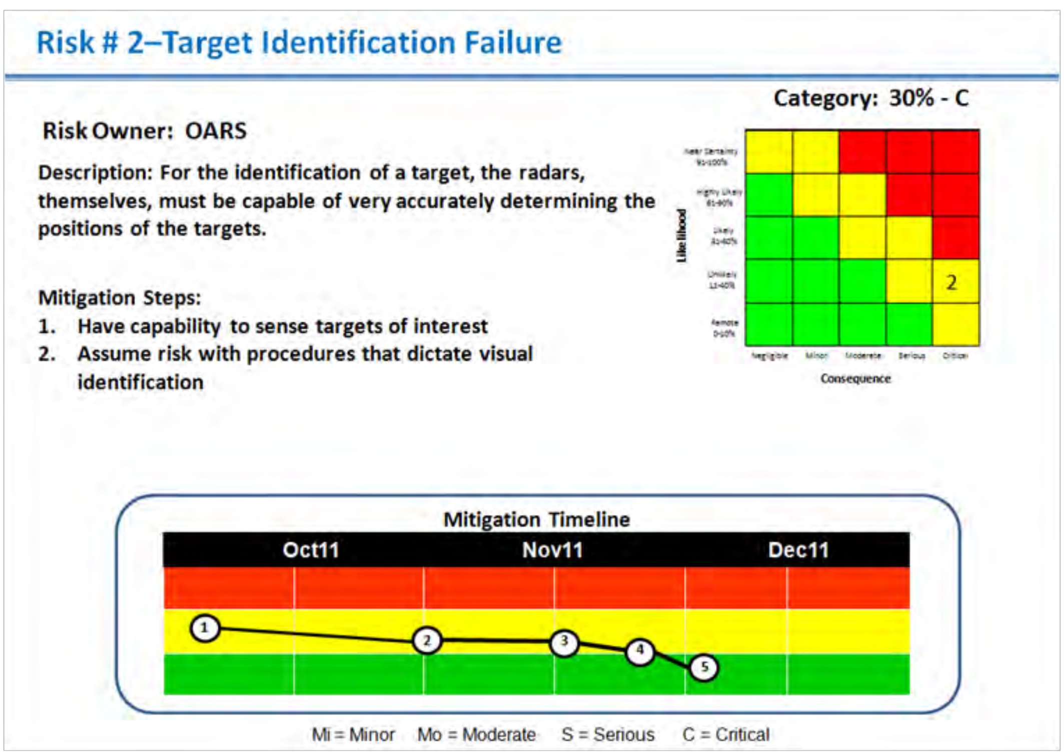


Figure 57. Risk #2: Target Identification Failure.

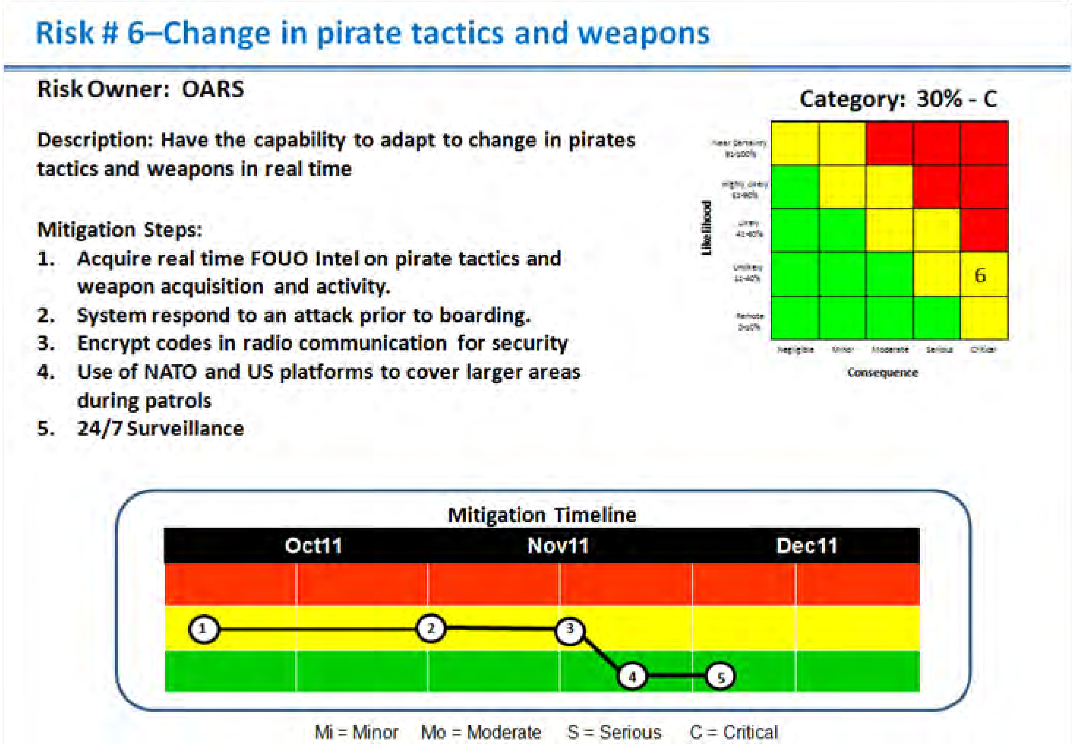


Figure 58. Risk #6: Change in Pirate Tactics and Weapons.

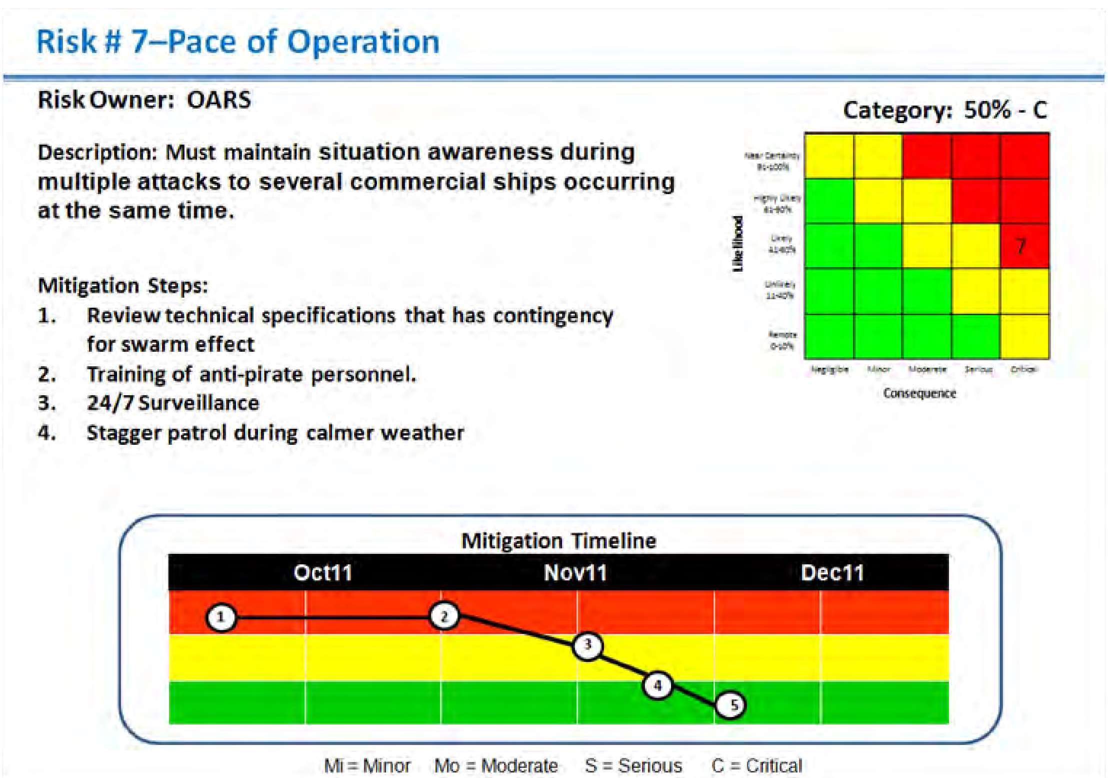


Figure 59. Risk #7: Pace of Operation.

APPENDIX E HOST SHIP COST COMPARISON

As discussed in Chapter II, Problem Definition, the Concept of Operations (CONOPS) of the OARS system includes coverage of 1.1 million square miles of ocean. In order to accomplish this feat, six host ships will need to be utilized. The OARS system‟s requirement for six host ships can be fulfilled by the use of many different naval vessels, including: LPD, LHA, LCC, CG, DDG, and FFG ships. However, the limited number of LPDs, LHAs, and LCCs in the U.S. Naval Fleet precludes the use of more than one of these capital ships in the Gulf of Aden OARS system. A procurement cost comparison to this six-ship system in the Gulf of Aden is presented in both Table 27 and Figure 60.

Table 27. Host Ship Combination Count for each Alternative.

Combo #	LCS	LPD	LHA	LCC	CG	DDG	FFG
1	6						
2		1			1	4	
3		1			1	3	1
4		1			1	2	2
5		1			1	1	3
6			1		1	4	
7			1		1	3	1
8			1		1	2	2
9			1		1	1	3
10				1	1	4	
11				1	1	3	1
12				1	1	2	2
13				1	1	1	3

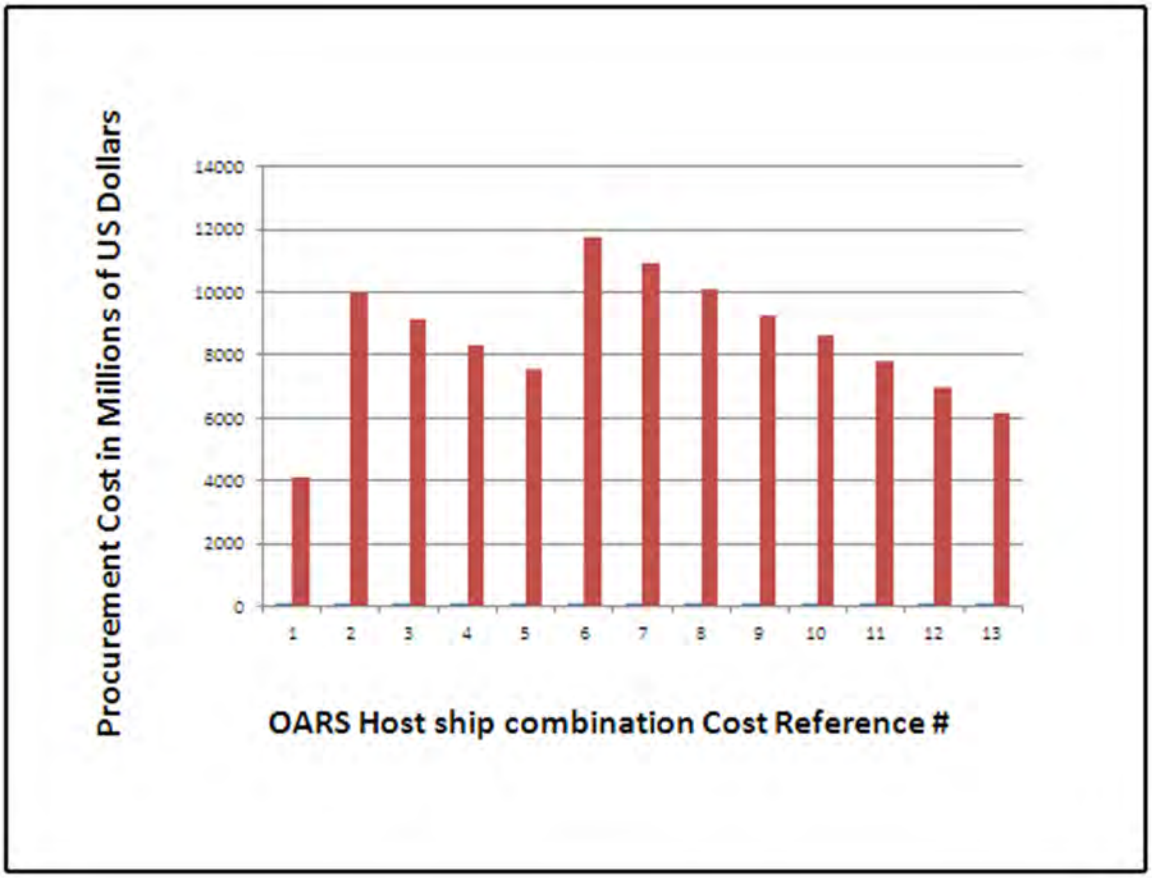


Figure 60. Costs of Alternatives to Host Ship Procurement.

Figure 60 shows that the procurement cost of Combination 1, which consists of six Littoral Combat Ships (LCS), is the least costly solution. For this reason, the OARS team utilized six LCS vessels in both of the OARS alternatives.

APPENDIX F TABLES USED IN COST ANALYSIS

Table 28. Functional Objective Area of Interest for OARS Sub-Systems.

Item	Quantity	Detection	C-3	L&T	Engage
LCS Ship	6		X	X	X
UAV's	9/12* 6	X			
SH-60	12	X	X	X	X
RHIB	12		X		X
50 Cal MG	12				X
BAMS	2	X	X	X	

Table 29. 2010 Inflation Rates from a NAVAIR Procurement. (taken from NCCA Inflation Indices 2010)

APN = Aircraft Procurement, Navy (1506)					
Base Year = 2010					2/24/2009
Fiscal Year	Inflation Rate %	Raw Index	Weighted Index	Budget Year Index	Budget Year Inflation Rate %
1996	2.00%	0.7901	0.8078	0.7890	1.40%
1997	1.80%	0.8043	0.8148	0.7957	0.86%
1998	0.70%	0.8100	0.8242	0.8050	1.16%
1999	0.80%	0.8164	0.8348	0.8153	1.28%
2000	1.40%	0.8279	0.8459	0.8261	1.33%
2001	1.80%	0.8428	0.8560	0.8360	1.19%
2002	0.80%	0.8495	0.8668	0.8466	1.26%
2003	1.00%	0.8580	0.8841	0.8635	2.00%
2004	2.00%	0.8752	0.9074	0.8863	2.64%
2005	2.80%	0.8997	0.9330	0.9112	2.81%
2006	3.10%	0.9276	0.9588	0.9364	2.77%
2007	2.70%	0.9526	0.9812	0.9583	2.33%
2008	2.40%	0.9755	0.9959	0.9726	1.50%
2009	1.50%	0.9901	1.0089	0.9853	1.31%
2010	1.00%	1.0000	1.0239	1.0000	1.49%
2011	1.40%	1.0140	1.0413	1.0170	1.70%
2012	1.70%	1.0312	1.0599	1.0351	1.78%
2013	1.80%	1.0498	1.0790	1.0538	1.80%

Table 30. Collection of Procurement and LLCs by Reference Year (various).

Item	Acquisition $ M or K/unit	O&S $ M or K / unit	Quantity	Lifecycle	O&S 6 sys/yr $M	LCC 6 sys $M	FY Price
LCS Ship[5]	680 M/ship	43 M	6	25 years	258	7950	FY10
UAV's[4,12]	7 M/12	$3.942 M	6	15 years	47.304	793.56	FY 06
SH-60[6]	42.417 M/A.C	28 M/ a/c	12	4.5 years	336	5549.004	FY04
MQ-8B[7]	16.2 M	1.97 M	12	10 years	23.65	549.2	FY06
RHIB[8]	100K	3.65 M/ yr	12	10 years	43.8	658.2	FY11
50 Cal MG[9]	14.00k/Gun	2.8k/gun	12	15 years	0.0336	0.504	FY11
BAMS[10]	220 M	169.83	2	15 years	339.6626667	2,547.47	FY11
50 Cal Ammo[11]	1.85 K/1,000=1.85 M/ Million	N/A	1 M	15 years	1.85	1.85	FY 11

The above table was used to collate the data from various element procurement and then life-cycle costs by reference year (various).

Table 31. Costs Set to Base Year FY11 from Procurement Costs and LCCs.

Item	Acquisition $ M or K/unit	O&S $ M or K / unit	Quantity	Lifecycle	O&S 6 sys/yr $M	LCC 6 sys $M	FY Price
LCS Ship[5]	689.52 M/ship	43.602 M	6	25 years	261.612	8004.18	FY11
UAV's[4,12]	7.65 M/12	$4.31 M	6	15 years	51.71	775.61	FY 11
SH-60[6]	49.14 M/A.C	32.44 M/ a/c	12	4.5 years	389.26	5838.95	FY11
MQ-8B[7]	17.71 M	2.15 M	12	10 years	25.85	600.32	FY11
RHIB[8]	100K	3.65 M/ yr	12	10 years	43.8	658.2	FY11
50 Cal MG[9]	14.00k/Gun	2.8k/gun	12	15 years	0.0336	0.504	FY11
BAMS[10]	220 M	169.83	2	15 years	339.6626667	2,547.47	FY11
50 Cal Ammo[11]	1.85 K/1,000=1.85 M/ Million	N/A	1 M	15 years	1.85	1.85	FY 11

The above table was used to inflate costs to a base year FY 2011 from various element procurement and then life-cycle costs.

Table 32. Alternative 1 Cost per Life Cycle Year.

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	Totals
Procurement	$ 1,000	$ 1,970	$ 1,000	$ 600	$ -	$ -	$ -	$ -	$ -	$ 680	$ -	$ -	$ -	$ -	$ 720	$ -	$ -	$ -	$ -	$ -	$ 5,967
Integration	$ -	$ 300	$ 600	$ 360	$ 140	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,400
Logistics	$ -	$ -	$ -	$ -	$ 296	$ 297	$ 298	$ 299	$ 300	$ 301	$ 302	$ 303	$ 304	$ 306	$ 308	$ 310	$ 312	$ 313	$ 313	$ 313	$ 4,894
Operations	$ -	$ -	$ -	$ -	$ 210	$ 211	$ 212	$ 213	$ 214	$ 215	$ 216	$ 217	$ 218	$ 219	$ 220	$ 221	$ 212	$ 120	$ 60	$ -	$ 2,949
Maintenance	$ -	$ -	$ -	$ -	$ -	$ 13	$ 14	$ 15	$ 16	$ 17	$ 18	$ 19	$ 20	$ 21	$ 22	$ 23	$ 24	$ 10	$ 7	$ -	$ 239
Disposal	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 5	$ 10	$ 15

Table 33. Alternative 2 Cost per Life Cycle Year.

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	Totals
Procurement	$ 980	$ 1,780	$ 750	$ 100	$ -	$ -	$ -	$ -	$ -	$ 599	$ -	$ -	$ -	$ -	$ 824	$ -	$ -	$ -	$ -	$ -	$ 5,033
Integration	$ -	$ 298	$ 648	$ 428	$ 138	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,512
Logistics	$ -	$ -	$ -	$ -	$ 385	$ 385	$ 386	$ 387	$ 388	$ 389	$ 390	$ 391	$ 392	$ 393	$ 394	$ 395	$ 396	$ 397	$ 398	$ 398	$ 6,264
Operations	$ -	$ -	$ -	$ -	$ 298	$ 299	$ 300	$ 301	$ 302	$ 303	$ 304	$ 305	$ 306	$ 307	$ 308	$ 309	$ 310	$ 140	$ 100	$ -	$ 4,192
Maintenance	$ -	$ -	$ -	$ -	$ -	$ 55	$ 55	$ 56	$ 56	$ 57	$ 57	$ 58	$ 58	$ 59	$ 59	$ 60	$ 60	$ 35	$ 15	$ -	$ 737
Disposal	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 7	$ 12	$ 19

Table 34. Spreadsheet used to Normalize FY11 Costs.

Item	Acquisition $ M or K/unit	O&S $ M or K / unit	O&S 6 sys/yr $M	LCC 6 sys $M	Inflation Scale
LCS Ship[2]					
FY10	680.00	43.00	258.00	3870.00	Inflation Rate
FY11	689.52	43.60	261.61	3924.18	1.4
UAV's[1]					
FY06	7.00	3.94	47.30	793.56	Inflation Rate
FY07	7.19	4.05	48.58	814.99	2.7
FY08	7.36	4.15	49.75	834.55	2.4
FY09	7.47	4.21	50.49	847.06	1.5
FY10	7.55	4.25	50.99	855.45	0.99
FY11	7.65	4.31	51.71	867.43	1.4
SH-60[3]					
FY04	42.42	28.00	336.00	5040.00	Inflation Rate
FY05	43.60	28.78	345.41	5181.12	2.8
FY06	44.96	29.68	356.12	5341.73	3.1
FY07	46.17	30.48	365.73	5485.96	2.7
FY08	47.28	31.21	374.51	5617.62	2.4
FY09	47.99	31.68	380.13	5701.89	1.5
FY10	48.46	31.99	383.89	5758.34	0.99
FY11	49.14	32.44	389.26	5838.95	1.4

The above table was used to properly apply the 2010 inflation rates to system elements to normalize the FY11 pricing.

Table 35. Spreadsheet 1 used to Estimate CTF-151 Costs.

Ship	cost per Ship ($B)	total acquisition cost ($B)	added item (RHIB, UAV, Helo) ($B)	total added cost ($B)	LCC from acquisition factor	LCC 2010	LCC 2011 ($M)	Qty	TOC ($M)
DDG-51	$1.5050	$1.5050	$0.0882	$1.593	1.94	$3,042	$3,085	1	$3,084.59
FFG-7	$0.6710	$1.3420	$0.0008	$1.343	1.13	$1,500	$1,521	2	$3,042.00
LPD-17[#]	$1.2050	$1.2050	$0.0002	$1.205	1.37		$1,649	1	$1,649.44
Jianwei	$0.1540	$0.3080	$0.0008	$0.309	1.13		$349	2	$697.00
Ulsan	$0.1190	$0.1190	$0.0002	$0.119	1.13		$135	1	$134.70
Barbaros	$1.0140	$3.0420	$0.0272	$3.069	1.94		$1,967	3	$5,901.48
La Fayette	$0.3100	$0.6200	$0.0178	$0.638	1.13		$711	2	$1,421.31
Iroquois	$1.1590	$1.1590	$0.0119	$1.171	1.13		$1,323	1	$1,323.12
Floreal	$0.1860	$0.1860	$0.0122	$0.198	1.13		$224	1	$223.97
Totals	$6.32	$9.49	$0.16	$9.65	$12.03	$4,542.00	$10,963.13	14	$17,477.61
								LCC Grand Total	**$17,477.61**

Table 36. Spreadsheet 2 Used to Estimate CTF-151 Costs.

ship	Quantity	RHIB Boats	Cost RHIB ($M)	Helicopter	Cost Helicopter ($M)	UAV System	Cost UAV System ($M)	Total Cost ($M)
DDG-51	1	2	$0.100	2	$42.40	1	$3.20	$88.20
FFG-7	2	4	$0.100					$0.80
LPD-17	1	2	$0.100					$0.20
jianwei	2	4	$0.100					$0.80
Ulsan	1	2	$0.100					$0.20
Barbaros	3	6	$0.100	2	$42.40			$256.20
La Fayette	2	4	$0.100	2	$42.40			$170.00
Iroquois	1	2	$0.100	2	$42.40	1	$3.20	$88.20
Floreal	1	2	$0.100			1	$12*	$12.20

APPENDIX G HEAVY UAV WEIGHT VALUE FUNCTIONS

System specifications provide information needed to determine requirements and constraints for modules on each alternative for storage and handling purposes. This will help stakeholders determine which alternative module is most suitable for their needs. Specifications for each system include the weight (in pounds), and flight endurance (in hours). Research of system documentation was the most widely used method of determining the specifications. Confirmed system specifications, as well as best effort estimates, provided inputs to the OARS mission.

Specifications for each element reviewed using a value model can be found in Appendix G, Heavy UAV Weight Value Functions. An example value model for the UAV is shown in Figure 61. The attributes of this element were broken down into the following: Weight, Speed, Range, Endurance, Payload, and Maximum Altitude (height).

Figure 61. Alternative Match-Up of Life Cycle Costs.

Table 37 details the total measured value and the costs for each of the UAV elements under consideration. In order for decision makers to understand the raw data better, these data points were graphed in Figure 62 below.

Table 37. Lightweight UAV Costs versus Measure of Value.

Light-Weight UAV

	Cost $K	Value Measure Total
Silver Fox	50	0.225
Manta B	40.5	0.577
Scaneagle	120	0.696
Exdrone	110	0.5935

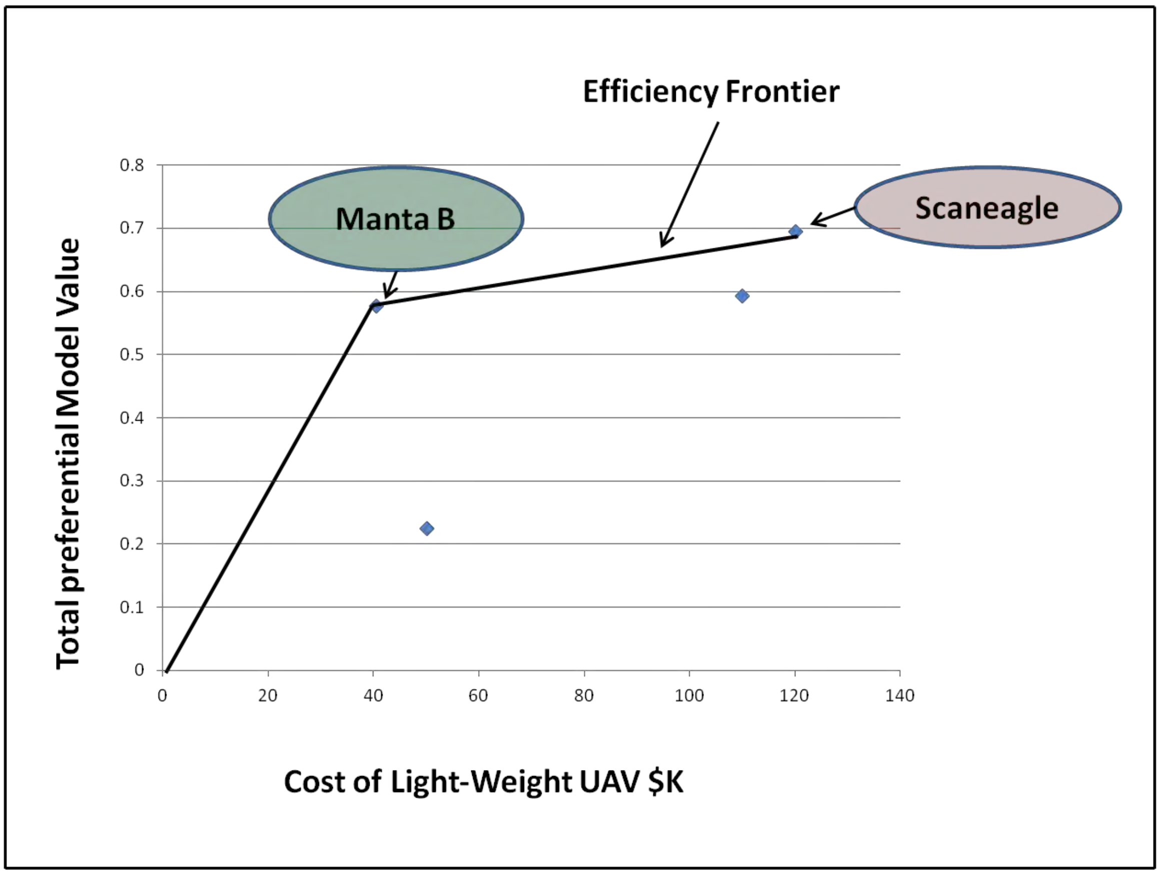


Figure 62. Alternative Match-Up of Life Cycle Costs.

The ScanEagle and Manta B UAVs were on the efficiency frontier in Figure 62. The data shows that the ScanEagle was the preferred choice between the two, due mostly to the preferred elevated endurance of the ScanEagle. The value preference model data and the corresponding characteristic attributes were exactly the same as the light UAVs as seen in Figure 61.

Table 38. Lightweight UAV Costs versus Measure of Value.

	Attribute Contribution to Overall Value Measure						Totals
Alternatives	Weight	Speed	Range	Endurance	Payload	Height	
Silver Fox	0.050	0.030	0.000	0.145	0.000	0.000	0.225
Manta B	0.007	0.136	0.188	0.105	0.016	0.126	0.577
Scaneagle	0.036	0.000	0.250	0.250	0.010	0.150	0.696
Exdrone	0.000	0.200	0.250	0.000	0.100	0.044	0.594

The Heavy UAV comparison of cost and value totals is shown in Table 39 below. The data applied to a graphic presentation can be found below in Figure 63. The data shows that two UAV systems appear in the efficiency frontier. The UAV system that stands out as the dominate system is the MQ-4C, which is located on the upper left quadrant. The Euro Hawk is slightly more expensive due mainly to the addition of export requirements that would be necessary for a European military market.

Table 39. Heavy UAV Costs versus Measure of Value.

Heavy UAV	Cost $M	Value Measure Total
MQ-4C-BAMS	210	0.3305
Global Hawk	220	0.73
Euro Hawk	221	0.869
Mariner (Predator B, BAMS)	N/A	N/A

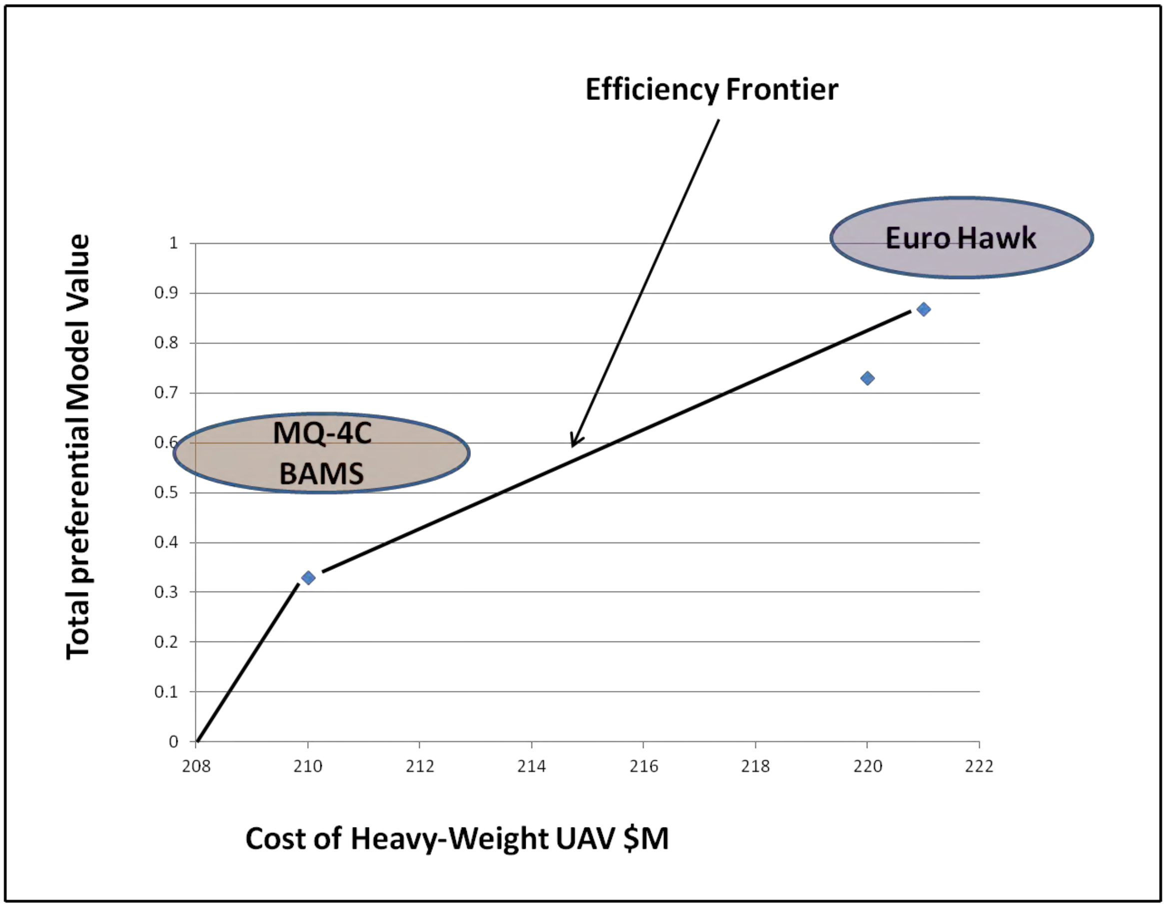


Figure 63. Heavy UAV Costs versus Preference Value Total.

The final selection of elements to the OARS system was with regard to the RHIB pursuit vessels. Appendix F contains the Value Functions for each attribute, which are: Payload, Speed, Range, Length, Weight, and Beam. These attributes make up the respective column headings in Table 40. Table 41 below matches the value totals with costs per RHIB.

Table 40. RHIB attribute Contribution to overall Value Measure.

Attribute Contribution to Overall Value Measure							Totals
RHIB	Length	Beam	Weight	Speed	Payload	Range	
USMI	0.010	0.018	0.013	0.020	0.005	0.285	0.351
Willard Marine, Inc.	0.010	0.000	0.000	0.000	0.200	0.000	0.210
ASIS	0.000	0.100	0.050	0.073	0.000	0.195	0.418
Zodiac Midline 3	0.100	0.025	0.028	0.250	0.024	0.300	0.727

Table 41. RHIB attribute Contribution to overall Value Measure.

RHIB	Cost $K	Value Measure Total
USMI	456.589	0.35
Willard Marine, Inc.	107.177	0.21
ASIS	94	0.42
Zodiac Midline 3	71.417	0.73

Figure 64 below presents the RHIB data via a graph and helps to explain the choices remaining for the RHIB selection process. The dominated region in the lower portion of the graph shows the elements that would not be preferred. The remaining system, the Zodiac, is above the "dominated region" due to its preferred characteristics. According to Figure 64, the Zodiac appears to be the clear winner.

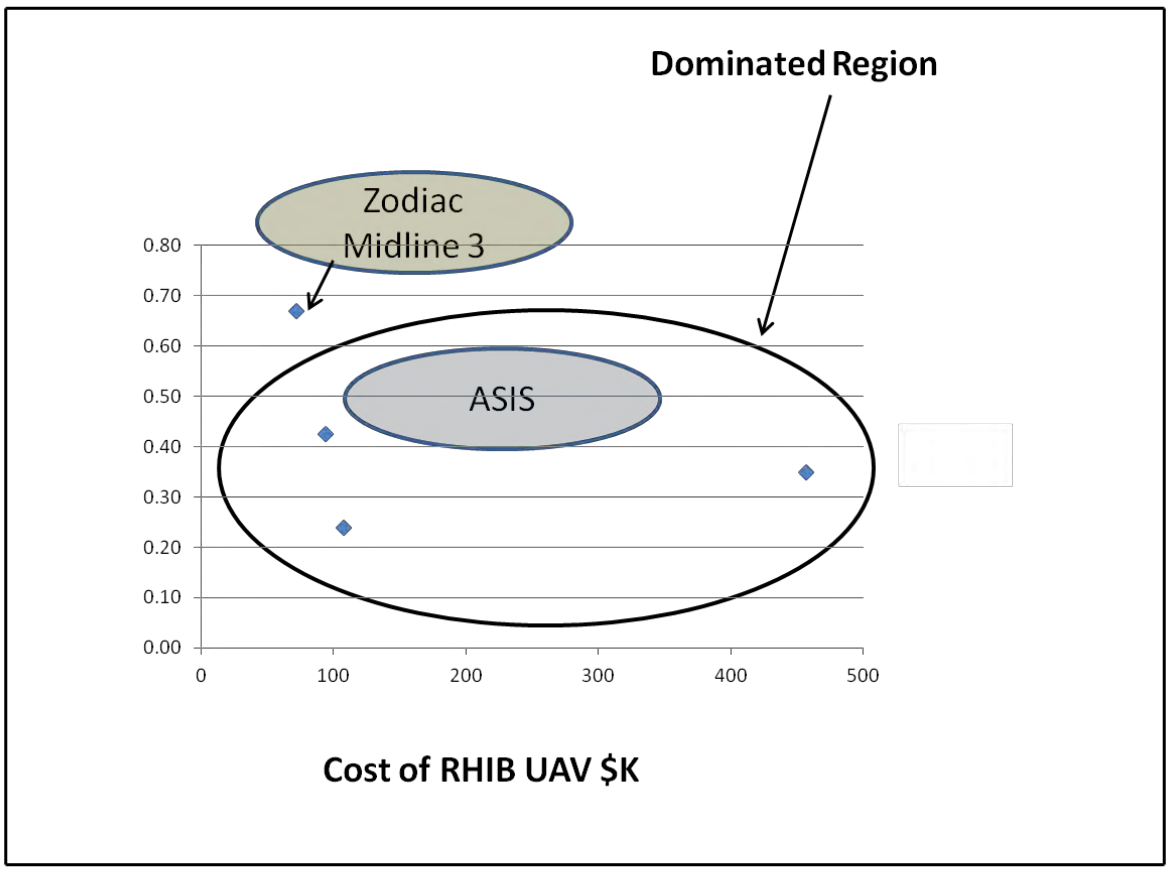


Figure 64. Heavy UAV Cost versus Preference Value Total.

Heavy Weight UAVs — **Atribute Data**

Alternatives	Max Gross Take off Weight	Range	Payload Capacity interior/exterior	Max Altitude	Max Endurance	Max Air Speed
	lbs	nm	lbs	ft	hrs	knt
MQ-4C-BAMS	32250	8200	5600	56500	28	331
Global Hawk	26700	11000	2900	65000	31	343
Euro Hawk	25600	12000	2000	65000	35	343
Mariner (Preda	10500	10000	3850	50000	30	240

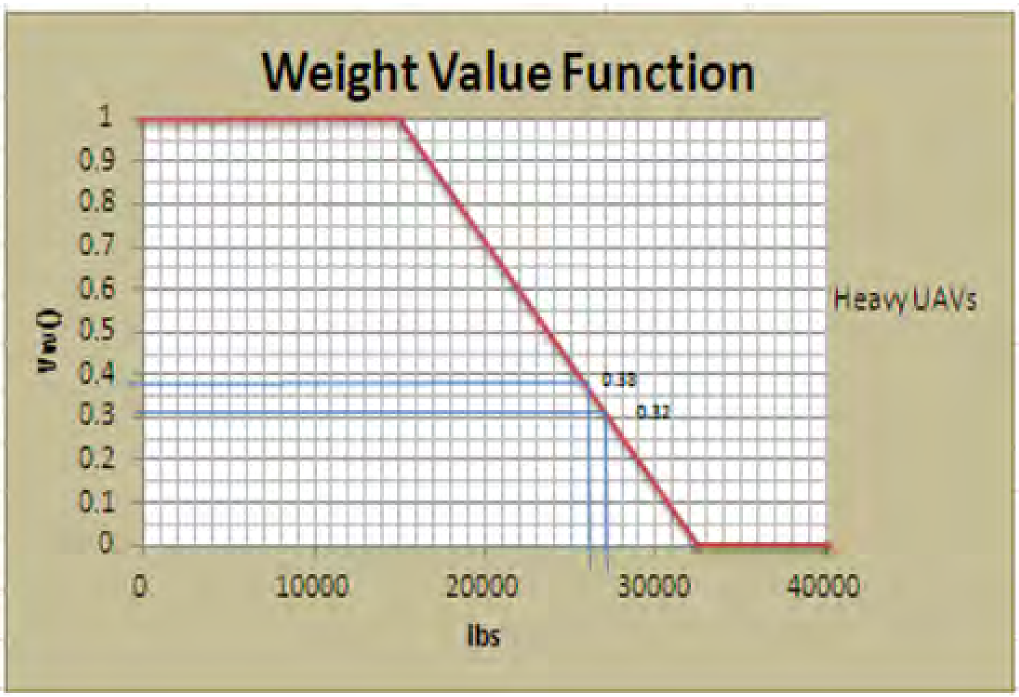
Attribute Data in Value Scale

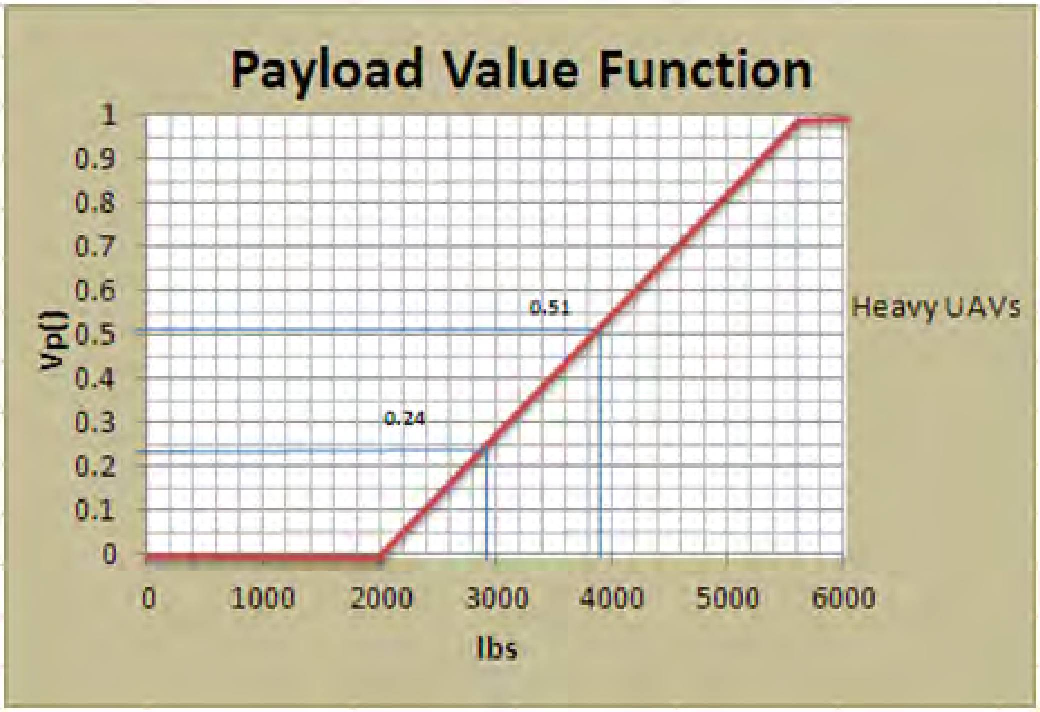
MQ-4C-BAMS	0.00	0.00	1.00	0.35	0.00	0.89
Global Hawk	0.32	0.98	0.24	1.00	0.44	1.00
Euro Hawk	0.38	1.00	0.00	1.00	1.00	1.00
Mariner (Preda	1.00	0.90	0.51	0.00	0.26	0.00

Attribute	Weight
Weight	0.05
Speed	0.20
Range	0.25
Duration	0.25
Payload	0.10
Height	0.15

Attribute Contribution to Overall Value Measure

							Totals
MQ-4C-BAMS	0.00	0.00	0.10	0.05	0.00	0.18	0.331
Global Hawk	0.02	0.25	0.02	0.15	0.11	0.20	0.745
Euro Hawk	0.02	0.25	0.00	0.15	0.25	0.20	0.869
Mariner (Preda	0.05	0.23	0.05	0.00	0.07	0.00	0.391

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0.7
0.6
0.5
0.4
0.3
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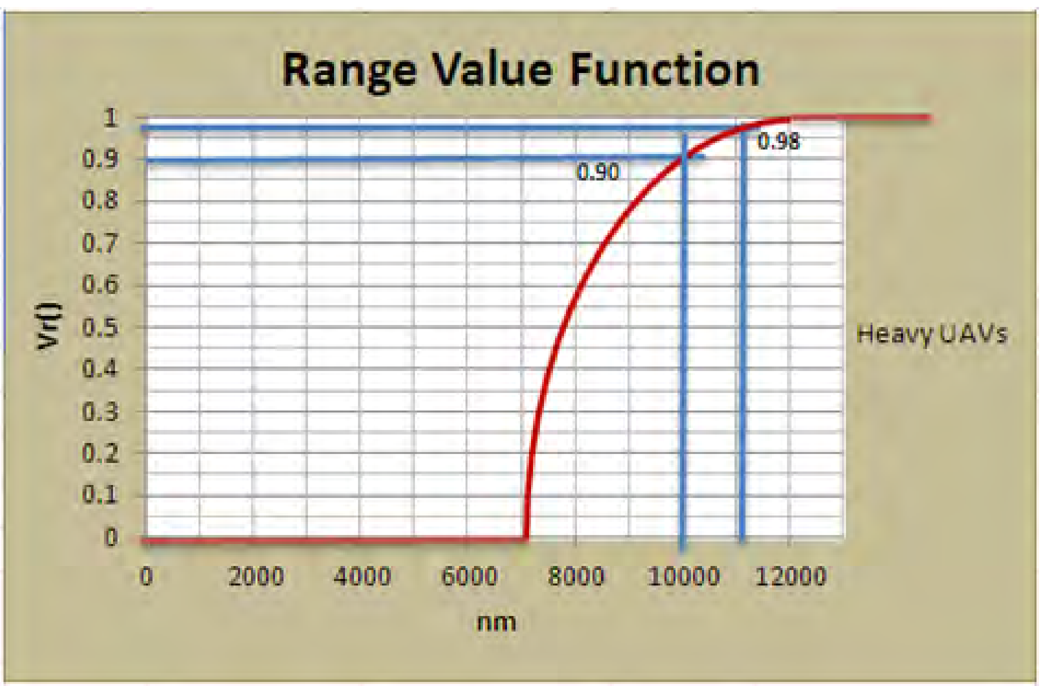
0.1
0
0.51
0.24
Heavy UAVs
0
1000
2000
3000
4000
5000
6000
lbs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0.8
0.7
0.6
0.5
0.4
0.3
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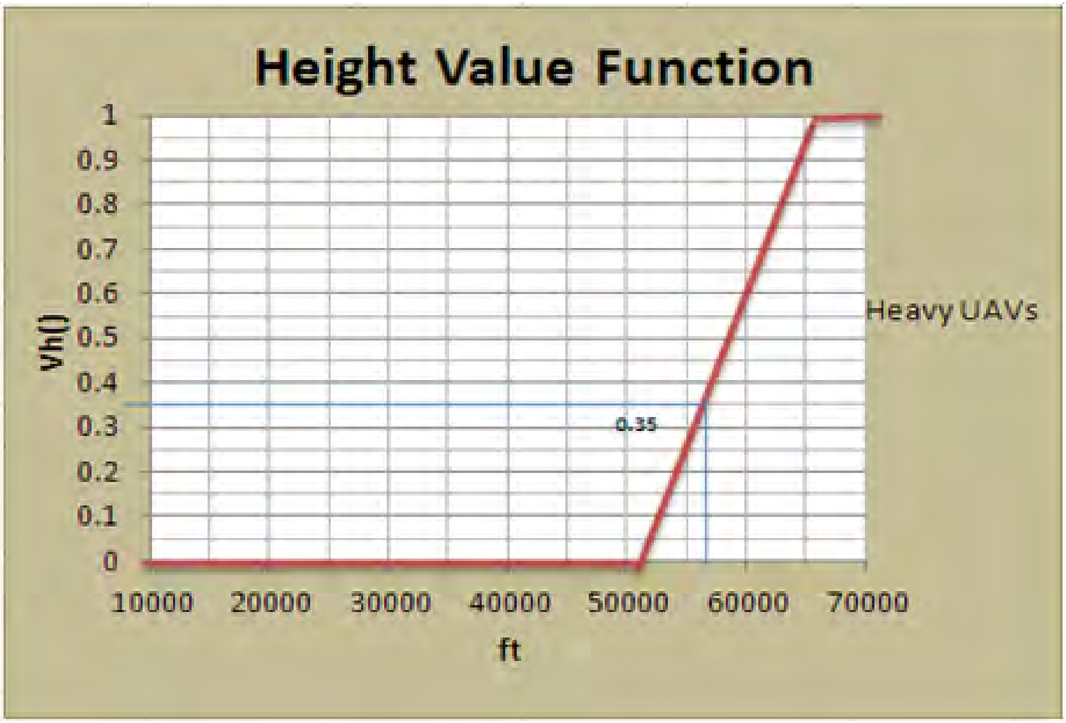
0.1
0
0.98
0.90
Heavy UAVs
0
2000
4000
6000
8000
10000
12000
nm


Height Value Function
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0.7
0.6
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0.4
0.3
0.2
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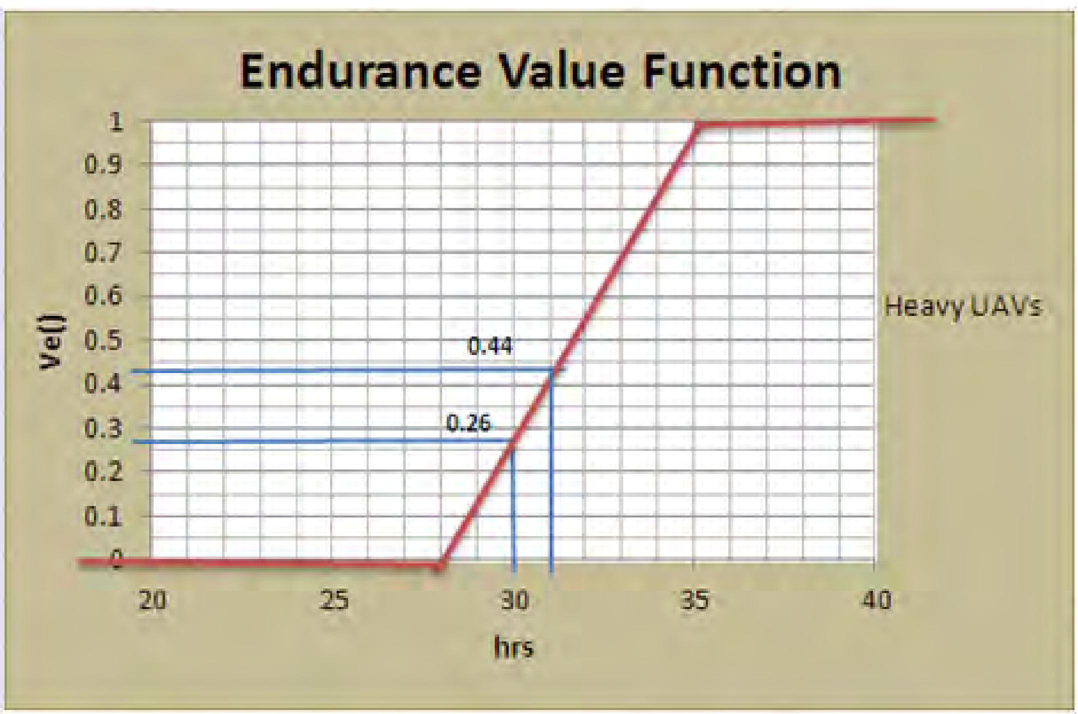
0
0.35
Heavy UAVs
10000
20000
30000
40000
50000
60000
70000
ft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0.8
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0.6
0.5
0.4
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0.2
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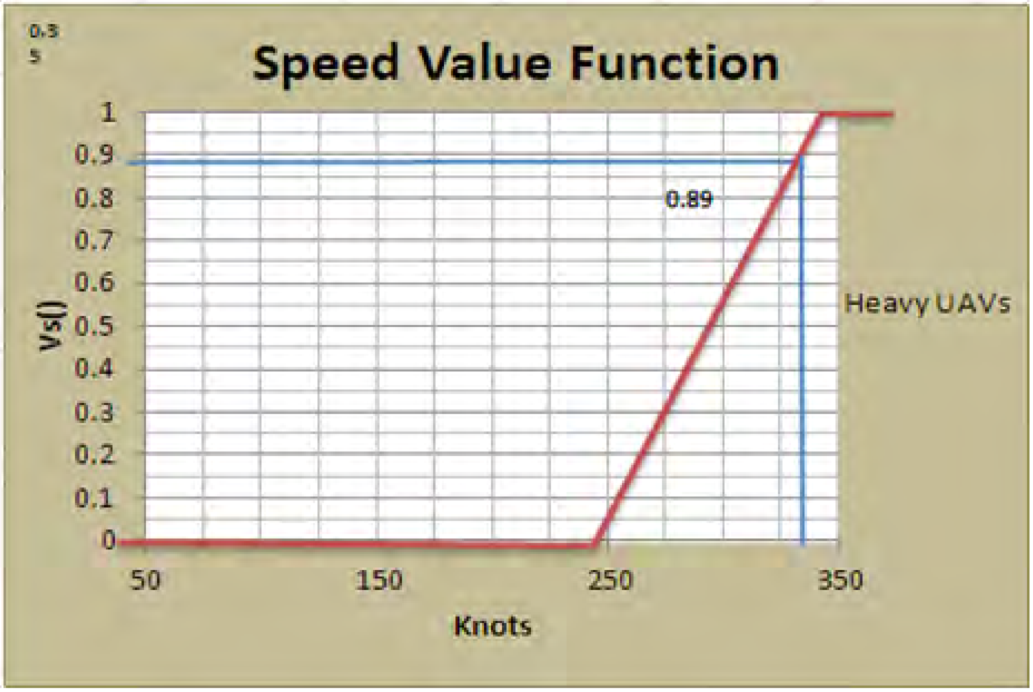
0.44
0.26
Heavy UAVs
20
25
30
35
40
hrs


0.3
5
Speed Value Function
1
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0.8
0.7
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0.5
0.4
0.3
0.2
0.1
0
Vs()
0.89
Heavy UAVs
50
150
250
350
Knots

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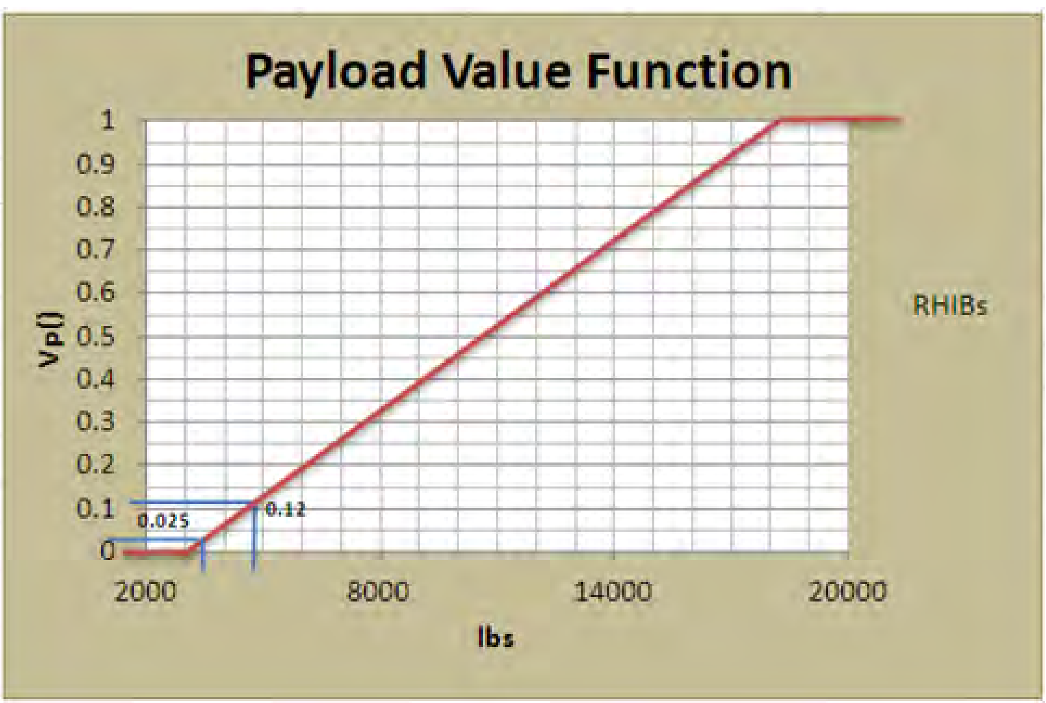
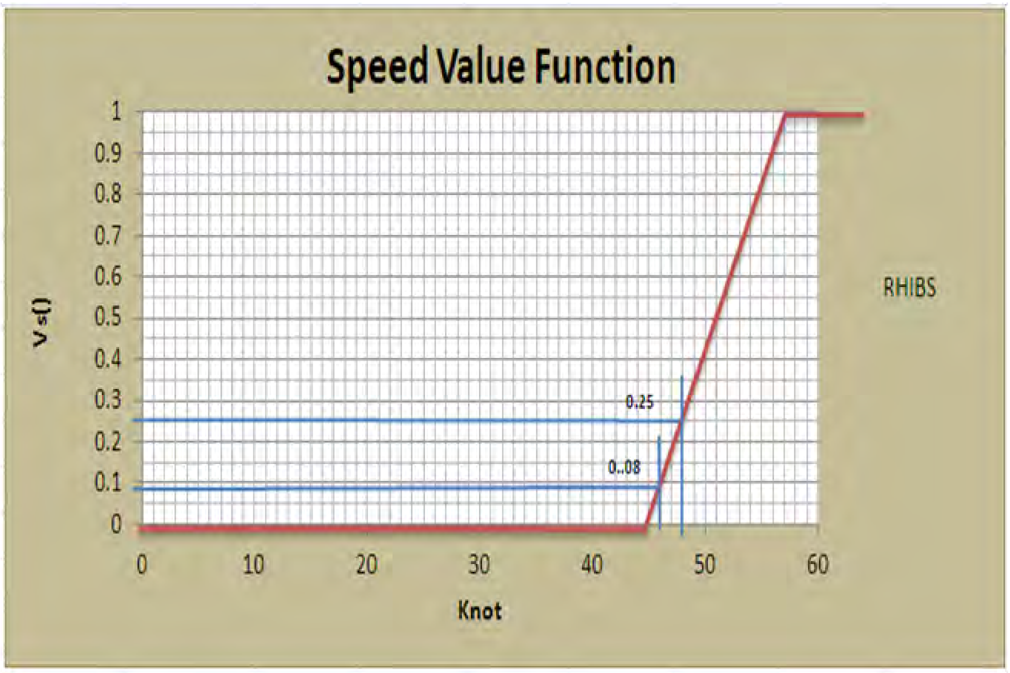
APPENDIX H RHIB WEIGHT VALUE FUNCTIONS

		RHIBS	Atribute Data							
		Manufacturer	Length	Beam (m)	Weight (lbs)	Speed (kts)	Payload(lbs	Range (nm)	Capacity	
		USMI	11.00	3.20	17,400	46.00	3200	200nm	13.00	
		Willard Marine, Inc.	11.00	3.70	22,000	45.00	18000	110nm	26.00	
		ASIS	9.80	3.10	3190	48.00	3000	127nm	21.00	
		Zodiac Midline 3	11.12	3.23	11155	57.00	4850	210nm	10.00	
			Attribute Data in Value Scale							
		USMI	0.820	0.180	0.250	0.080	0.025	0.990	0.200	
		Willard Marine, Inc.	0.820	0.000	0.000	0.000	1.000	0.000	1.000	
Attribute	Weight	ASIS	0.000	1.000	1.000	0.250	0.000	0.550	0.700	
Weight	0.150	Zodiac Midline 3	1.000	0.250	0.580	1.000	0.120	1.000	0.000	
Speed	0.200									
Range	0.250		Attribute Contribution to Overall Value Measure							Totals
Beam	0.050	USMI	0.041	0.009	0.038	0.020	0.005	0.248	0.020	0.360
Payload	0.200	Willard Marine, Inc.	0.041	0.000	0.000	0.000	0.200	0.000	0.100	0.241
Length	0.050	ASIS	0.000	0.050	0.150	0.063	0.000	0.138	0.070	0.400
Capacity	0.100	Zodiac Midline 3	0.050	0.013	0.087	0.250	0.024	0.250	0.000	0.674

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0..08
0
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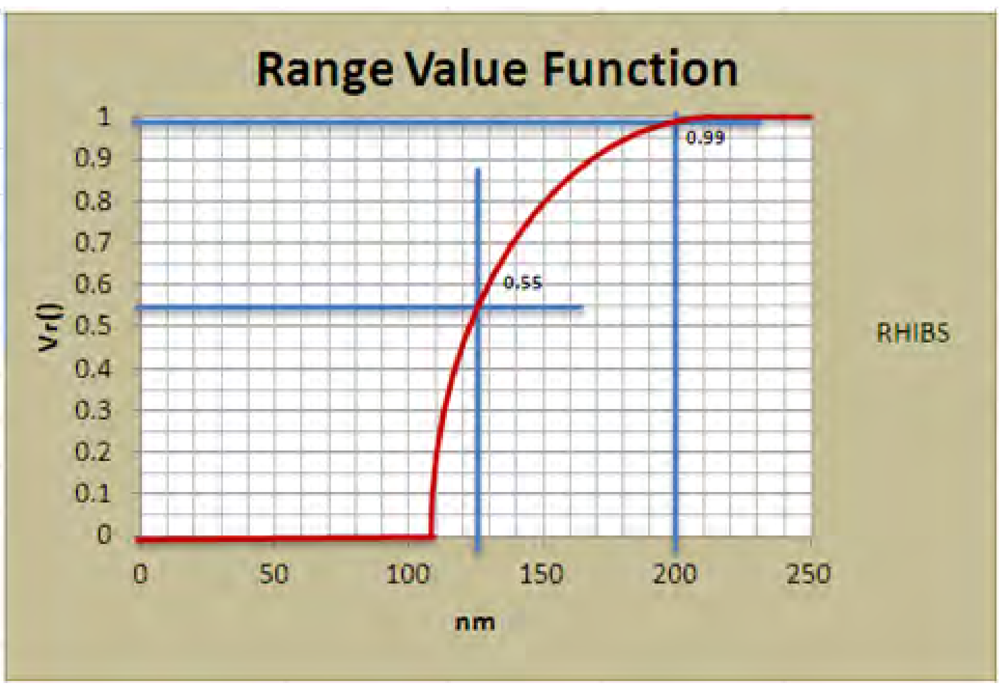
20
30
40
50
60
Knot
RHIBS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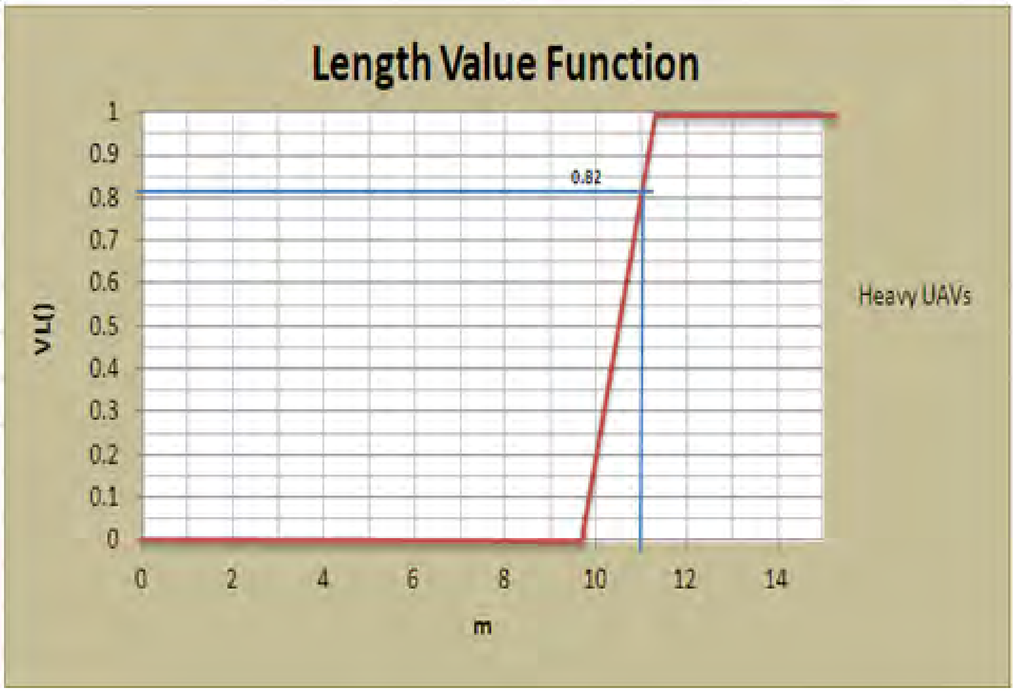
0.55
0
50
100
150
200
250
nm
RHIBS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0.3
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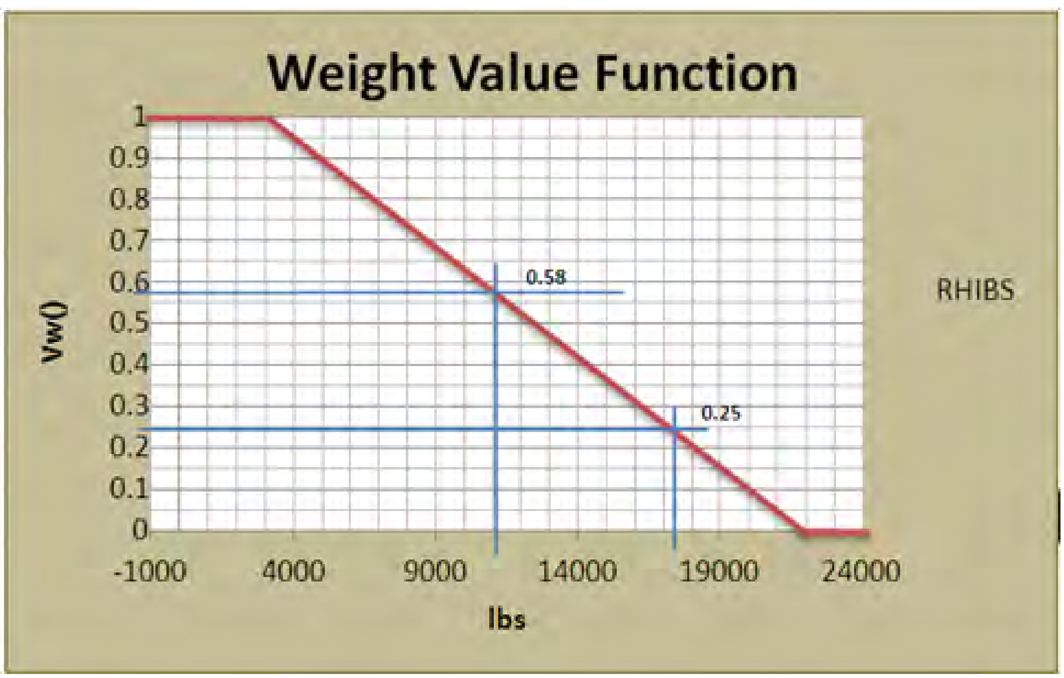
0
0.82
0
2
4
6
8
10
12
14
m
Heavy UAVs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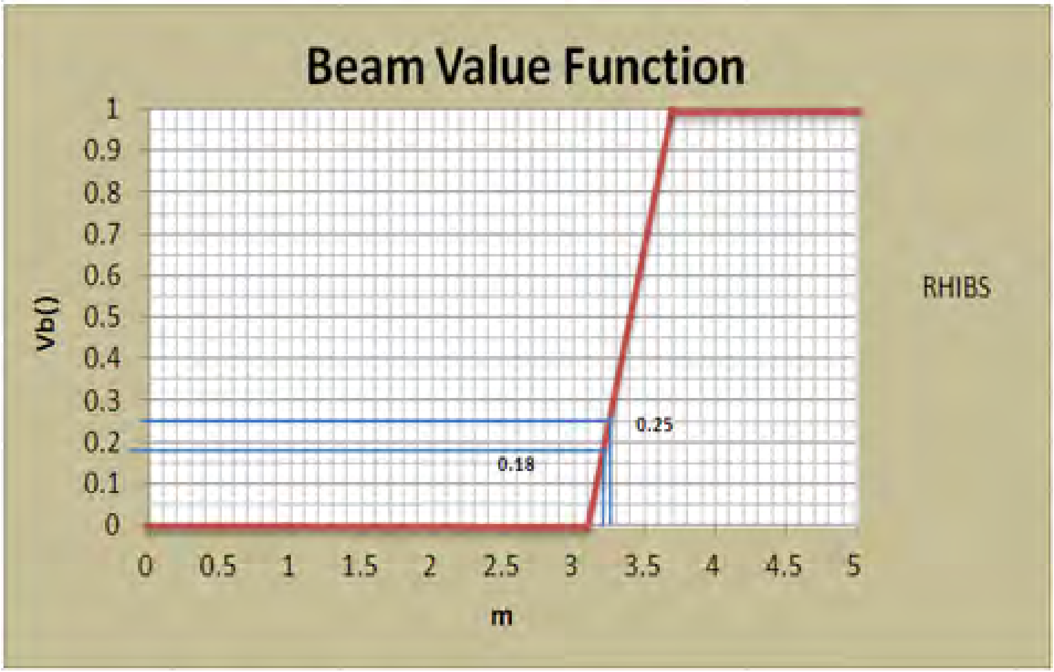
4000
9000
14000
19000
24000
lbs
RHIBS


Beam Value Function
Vb()
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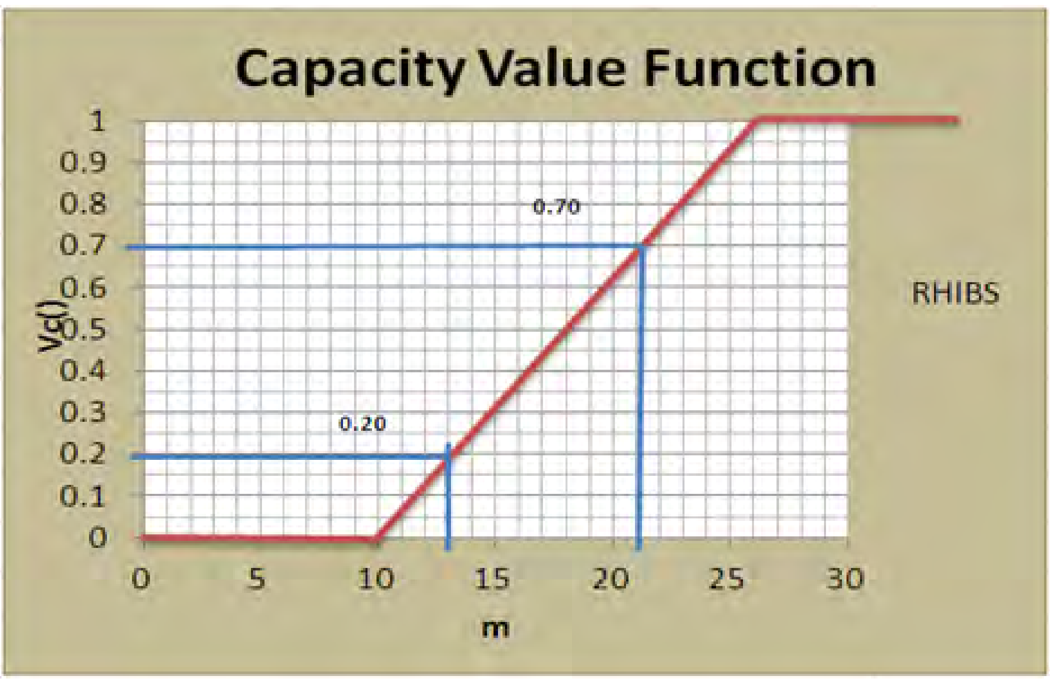
4.5
5


Capacity Value Function
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RHIBS
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0.2
0.1
0
0
5
10
15
20
25
30

APPENDIX I LCC OF THE OARS ALTERNATIVES BROKEN DOWN BY FUNCTIONAL OBJECTIVES

Each OARS alternative will procure systems according to the assessment made in the Recommended Alternatives section. Costs are displayed in four functional objective areas. Those areas are:

- Detection in patrol.
- Command, control & communicate.
- Localize and track.
- Engage.

Due to some similarities between the two OARS alternatives, each of them will tally similar costs in the "Detection in Patrol" category. This is due to the fact that both alternatives utilize similar modern UAV sensor packages. Contrastingly, the two alternatives have some costs that vary distinctly due to the fact that the augmented OARS alternative utilizes a Broad Area Maritime Surveillance (BAMS) system, whereas the Basic OARS system does not.

A. ALTERNATIVE #1, OARS BASIC

The cost of the primary search sensor, the UAV system, is roughly 13 times cheaper than all other detection system costs combined for Alternative 1. Procurement costs of the UAV systems are quite small compared to the overall procurement cost. The costs associated with procuring surface sensors are identical between both alternatives. All LCS platforms have the same radar, EADS-Air search, and Sea Giraffe-surface search capabilities, thus they all have the same costs.

Figure 65 shows the LCC of Alternative 1 broken out by functional objectives. The bulk of the costs center around the LCS host ship system and since Alternative 1 utilizes six host ships, this cost is very large.

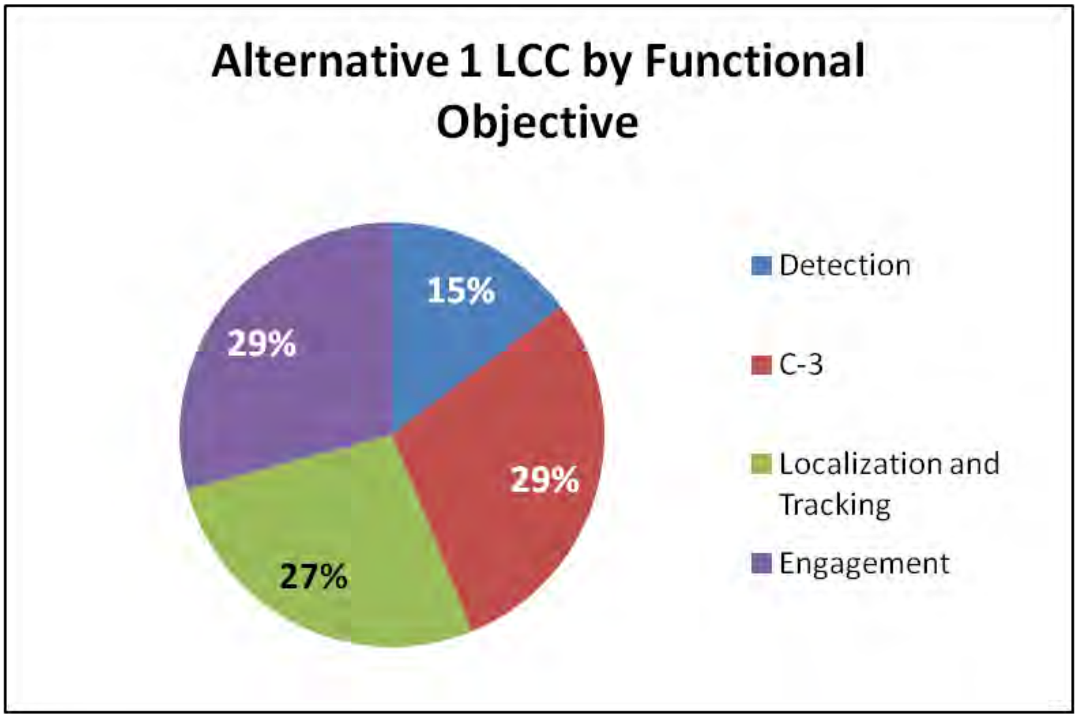

Figure 65. Alternative 1 LCC by Functional Objective.

B. ALTERNATIVE #2, OARS AUGMENTED

Procurement costs for Alternative 2 also consist of each of the four functional objectives. Figure 66 shows that this alternative allows the funding for surface sensors to grow in parity to the remaining three functional objectives. Due to the Alternative 2‟s addition of an air-borne surface sensor, the total procurement costs are increased, thus making this the more expensive alternative.

Airborne surface sensors remained the largest functional objective with 27% of the total costs. Airborne surface sensor costs are split between the SH-60 Helicopter and the UAVs, but the primary sensor is the UAV. Distribution of the remaining costs will weigh heavily on combat systems at 29%.

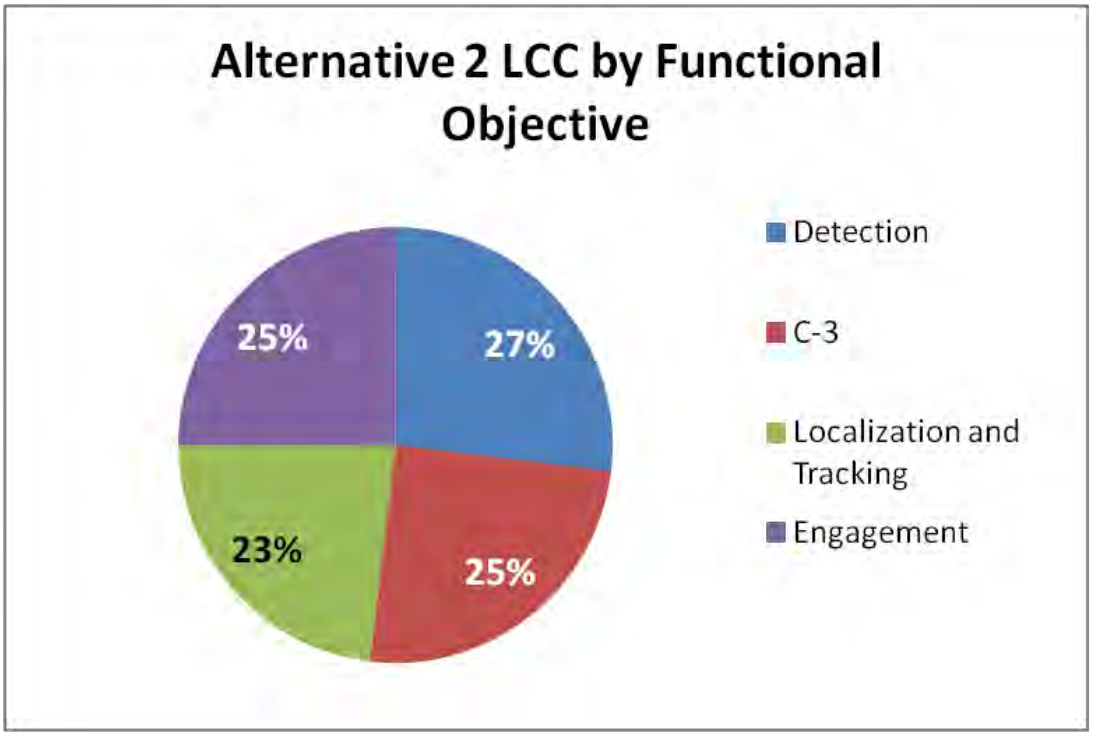

Figure 66. Alternative 2 LCC by Functional Objective.

The total funding amount is largely affected by the procurement cost of the host ship platforms. However, the addition of Alternative 2‟s BAMS system increases the procurement cost within the surface detection functional objective from 15% in Alternative 1 to 27% in Alternative 2. The Zodiac Rigid Hull Inflatable Boats (RHIB), which are utilized as pursuit vessels in both alternatives, represent the lowest procurement cost items in each of the alternatives at $0.852 Million. The .50 caliber machine guns represent roughly $2.032 Million of material that will be affixed and deployed on the RHIB boats. The RHIB gun element was priced with one million rounds in procurement. In contrast to the surface engagement RHIB boats, the primary airborne engagement element of the OARS system, the SH-60 Sea Hawk Helicopter, will assume roughly 16% of the procurement costs.

The introduction of the BAMS system accounts for 18% of the LCC at almost $3.2 billion. The preference model in Appendix G dictated the use of the Global Hawk or Euro Hawk BAMS vehicle from a superior flight endurance point of view.

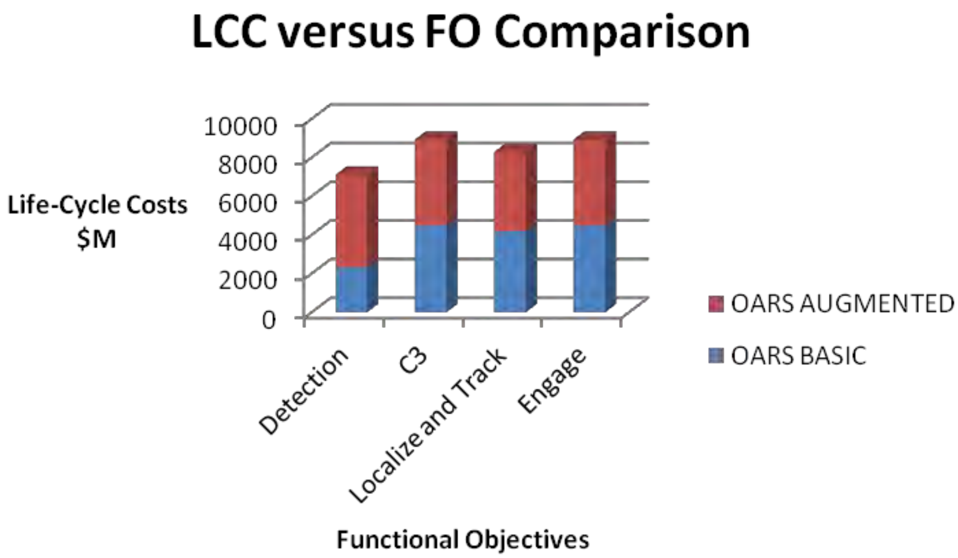

Figure 67. LCC versus Functional Objective Comparison.

Figure 67 and Table 42 illustrate a comparison of both OARS alternatives" Life Cycle Costs broken out by their functional objectives. As mentioned above, the OARS Augmented option was the most expensive option.

Table 42. LCC by Functional Objective Comparison.

Life-Cycle Cost by Function	Detection	C-3	Localization and Tracking	Engagement	Total
OARS BASIC	$ 2320 Million	$ 4484.6 Million	$ 4175.3 Million	$ 4484.6 Million	$ 15465 Million
OARS AUGMENTED	$ 4783 Million	$ 4439 Million	$ 4110 Million	$ 4438.5 Million	$ 17770.5 Million

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